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ABSTRACT

The roles of (1) the sequence of instruction and (2) cognitive ability variables were investigated using a computer-assisted instruction (CAI) course on an imaginary science of "Xenograde systems." A rationale for an information processing task analysis was developed to overcome the deficiencies of other analytic methods. The new method was found to have good reliability of sequence determination. An index, called the hierarchical sequence conformity index (HSCI), was constructed for quantifying the degree of conformity of the sequence of a particular presentation to the sequence determined by the information processing task analysis. When the HSCI was used to study the effect of three cognitive abilities (induction, reasoning, and memory) the results indicated that: induction appeared to contribute to performance on disordered sequences of instruction, reasoning ability affected performance on self-selected sequences, and memory appeared to have no effect on performance. Since selection of one's own sequence did not produce an increase in performance or interest, a predetermined hierarchical sequence may achieve the desired instructional goal as efficiently. (Author/JY)

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PROGRAM SEQUENCE BY ABILITY INTERACTION IN LEARNING A HIERARCHICAL TASK BY COMPUTER-ASSISTED INSTRUCTION

William P. Olivier

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13. ABSTRACT

The sequence of instruction in a fixed set of highly controlled learning materials was investigated. Computer-assisted instruction (CAI) was used to administer the instructional materials and to collect the data. The role of some cognitive ability variables was also investigated. (U)

A survey of the literature showed that there were several ways of analyzing the task to determine its structure. This analysis then should prescribe the sequence of instruction. In general, it was found that a disordering or scrambling of this analyzed sequence made little difference on the student's performance. The methods for analyzing the task did not always yield the same sequence, depending upon who performed the analysis. The rationale for an information processing task analysis was outlined to overcome the shortcomings of the other analytic methods. The new method appeared to have good reliability of sequence determination (i.e., different persons derived the same sequence using this method).(U)

Several studies have indicated that students can effectively sequence the learning task for themselves. In order to determine how their selected sequences affected their performance, it was necessary to quantify their different sequences. An index for quantifying the degree of conformity to the information processing sequence was developed. This index was called the hierarchical sequence conformity index.(U)

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The task used was an imaginary science. This task was easy to learn, and no subjects had previous knowledge of the materials. It was a way of using somewhat meaningful materials while retaining experimental control.

Computer-assisted instruction provides a means of individualizing instruction with the goal of maximizing each individual's performance. To provide information about some individual difference variables which may be related to instructional sequence, certain cognitive abilities were measured.

One hundred seventy-six undergraduate education majors were given eight tests to measure the abilities of Induction, Associative Memory, and General Reasoning. A principal axis factor analysis followed by a varimax rotation yielded three factors which were interpreted as clearly representing the abilities.

Factor extension procedures indicated the relative loadings of the criterion measures on the three abilities. Induction appeared to contribute to performance for disordered sequences of instruction, and General Reasoning for self-selected sequences.

Selection of one's own sequence did not produce any increase in performance or interest; therefore, a predetermined hierarchical sequence may achieve the desired goal as efficiently.

PROGRAM SEQUENCE BY ABILITY INTERACTION IN LEARNING A HIERARCHICAL TASK BY COMPUTER-ASSISTED INSTRUCTION

by

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Austin, Texas
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W.P.O.

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CHAPTER 1

INTRODUCTION

In a traditional classroom the teacher mediates a subject to the students by selecting, organizing, dispensing, and testing information and skills. A one-to-many relationship exists between the subject matter, mediated by the teacher, and the students. The teacher must try to reach the largest number of students in a group as possible. This usually means the teacher must direct the instruction to the average student.

A goal of education is to be able to maximize each individual's performance whether this performance be proficiency on a task immediately following learning, retention over a period of time, efficiency or amount learned per unit time, the ability to transfer skills acquired in the learning experience to a new situation, enjoyment of the learning experience, or any combination of these.

A current trend is to "individualize" instruction or to use each individual rather than a group as the target unit. When the individual becomes the unit, then the instruction should be aimed at this individual rather than to a hypothesized average student, who might or might not coincide with the individual under consideration.

The purpose of this study is to investigate one aspect of individualized instruction; namely the organization and sequence of information. The relationship of the structure of the academic learning task to the sequence in which this information or set of skills is presented to a given individual is the main concern of this investigation.

A computer-assisted instruction (CAI) environment was chosen for this research because a one-to-one ratio between the subject matter and the student could be achieved. The use of a computer standardized the presentation within each treatment group and facilitated data collection and data reduction.

A review of studies related to the structure of the subject matter, methods of sequencing the instruction, and individual learner differences follows.

Methods for Determining Task Structure

A task structure could be defined as the ordered relationship of sub processes or subtasks which constitute the task. Various means for analyzing a task into its ordered units have been proposed. Implicit in these attempts to impose a structure on a task is the assumption that following this structure during learning will maximize the learner's performance. Two types of structural analysis: content analysis, and behavioral task analysis were reviewed.

Content analysis. A subject matter expert might perform the analysis of a given task in terms of the content to be learned. This type of content analysis may be referred to in general terms as a "logical" analysis and may take several specific forms. For most academic education some variant of this method has usually been followed.

In the analytic approach content progresses from general to specific, while the synthetic method reverses the sequence and goes from specific to general. Time ordering, sometimes called a chronological sequence, has also been used. The chronological analysis has generally been used in subject matter fields like history. Sequence in terms of a progression of "natural units" has been yet another method. This list was not intended to be inclusive.

Task analysis. Behavioral task analysis arose as a response to military training needs. Miller (1953) was one of the early proponents of this approach. Basically a specific behavioral description of the desired performance must be made and this description can be placed in categories which have differential training implications. This approach was expanded to include the sequencing of subtasks by Mechner (1967) and Gagné (1962, 1968a).

A behavioral analysis was proposed by Mechner (1967) in terms of discriminations, generalizations, and chains. This analysis classifies learning into three behavioral categories and assumes that this progression of behavior is necessary for instruction. The behavioral analyst in this scheme is to imagine a typical student asking questions about the material to be learned. The analyst then asks himself if the student would be likely to ask the question, and if so at what level should the question be answered? In this scheme the analyst is to try to keep in mind the target population of learners and the set of behaviors the learners should have available. This analysis is somewhat subjective, because it depends upon the skill and perception of the behavioral analyst in determining characteristics of the learners.

Gagné (1962) proposed a task analysis which would yield a hierarchy, or ordered structure, of subtasks necessary before the terminal objective could be reached. This type of analysis should produce a hierarchy of skills related to the subject matter. Gagné felt that there were characteristics of a given task which dictated the appropriate sequence of learning. In making this type of task analysis one would work backwards through the task to determine what was prerequisite of each higher stage. This type of analysis was proposed as a way of understanding the learning of subject matters such as mathematics and science. The structures of science and mathematics usually have been considered to be hierarchial.

Recently Gagné (1968a) revised his general categories of learning which can be represented as different levels in a hierarchy. The revised sequence for instruction was from establishing S-R connections to chains (motor and verbal), multiple discriminations, concepts, simple rules and finally complex rules. Gagné felt that perhaps even a ten-year-old child was mainly involved in learning only rules and concepts. Presumably all necessary lower behaviors have been learned by this age. The implication was that the sequence of concept to simple rule to complex rule was the only subset of the behavior hierarchy of interest to the instructional designer concerned with high school and college level students.

The methods described above were attempts to define procedures for assigning a structure to a task. A literature survey indicated that various attempts have been made to validate or invalidate the benefits of an imposed task structure.

Methods of Sequencing Instruction

Many studies have addressed questions such as whether to provide branches around certain materials and when to give review. The current investigation was limited to the question of the ordering of a set of well-defined subtasks within a task, rather than investigating the effects of the size, number, or type of items in a set.

Two general classifications of interest arose from the literature survey. First, situations in which the sequence of instruction has been determined in advance and administered to the student at the time of learning, and second, those situations where the student has been allowed to select his own sequence by interacting with the learning materials were noted.

Predetermined sequence studies. Most learning situations have involved a predetermined sequence of instruction. The following study was an attempt to show that an ordered flow was necessary. Gagné (1962) showed an analysis of the scores at each level of an ordered task for seven ninth grade boys. The task was to develop formulas for finding the nth term in a number series. All Ss were progressed from the lowest level of the task upward through the task structure toward the terminal objective. The analysis indicated that for the highest level passed all lower levels were passed. This study did not provide positive evidence for the necessity of an ordered sequence; although some of the deductions were supported. No negative instances of the deductions were found. It should be stressed that only seven Ss were used and no comparisions were made to a control group. Although the necessity of a fixed sequence through the task's structure was not disconfirmed it was not completely confirmed either. In contrast, Merrill (1965) did not find it efficient for Ss to achieve mastery at a given level before proceeding to a higher level. Forcing Ss to review and repeat a level did not significantly increase scores on a posttest.

Research on the effects of presequenced academic tasks has involved most often a comparison to a disordered or scrambled sequence.

Scrambled sequence studies. There have been a number of studies (Hamilton, 1964; Levin & Baker, 1963; Payne, Krathwohl & Gordon, 1967; Roe, 1962; Roe, Case, & Roe, 1962; and Wodtke, Brown, Sands & Fredericks, 1968) that used a method of randomizing or scrambling the instructional sequence from a predetermined ordered sequence. Many of the studies (Hamilton, 1964; Levin & Baker, 1963; Payne et al., 1967; and Roe et al., 1962) have failed to find any significantly detrimental effect of scrambling a "logical" sequence. Wodtke et al. (1968) found slight effects of randomizing the sequence.

Wodtke et al. (1968) found a small effect of scrambling the sequence for an ordered task, a program on number bases. No performance decrement resulted when another task, a program on the anatomy of the ear, was presented in a scrambled sequence. The effect of sequence on the ordered task was most pronounced early in learning, as reflected by errors made during instruction. By the end of the task the randomly sequenced group was actually making fewer errors than the group which took the task in the ordered sequence.

The authors did not conclude that the instructional designer should entertain the notion of actually using the method of random sequencing, but rather that the importance of sequencing may have been overstressed, especially for certain types of tasks.

Neidermeyer (1968) reviewed studies on random sequencing and concluded that at least for relatively short instructional sessions the importance of frame sequencing has been overstressed.

Roe et al. (1962) suggested that scrambling the sequence increased motivation to master the task, and the increased motivation helped to equate the groups on terminal performance. The suggested source of this motivation was task oriented anxiety which was relieved when the answer was later supplied. Payne et al. (1967) offered another tentative hypothesis. The latter authors believed that the students relied on the cognitive processes of memory and inductive reasoning when they received a scrambled sequence.

Learner selected sequences. The first reported study that allowed the student to select his own sequence through the learning material was a study by Mager (1961). The purpose of the original study was exploratory, not experimental. Mager wanted to see if a learner-generated sequence would parallel an instructor-generated sequence, and if there were any common sequences selected among learners.

Six Ss were given neither specific sequences nor specific objectives in the task. Each S was told that he could ask any questions that he wished on the field of electronics, and that he could also spend as much time as he wished at this task. Mager found that the Ss did not sequence the material as it was typically sequenced, nor was the content the same, although there seemed to be some communality in the sequences that Ss followed. Although all Ss claimed no knowledge of the subject matter, it was found that they did in fact know more than they admitted. It was also found that although instructor-generated review was rebuffed, several students initiated review on their own and used the instructor as a knowledge of results mechanism. Mager suggested that the learner's motivation was increased as his amount of control or apparent control over the learning increased. Motivation as used here apparently means the frequency or vigor of content approaching responses made by the learner. It was also held that the meaningfulness of the material was increased by the self-sequencing instructional method. No claim was made that the self-sequencing instructional method was more efficient or effective than a pre-selected sequence. Such a claim could not have been supported by the design used. It must be remembered that the six Ss generated not only their own sequence but their own objectives as well. It should be noted also that since no specific objectives were given, the student learned only as much as he desired to learn and only those aspects which were of interest to him.

In another study (Mager & McCann, 1961) highly specified terminal objectives were used with graduate engineers in an industrial training situation, and the effect of student-selected sequencing was assessed. In comparison to a formal course group used previously, the training time was reduced 65 percent. The graduates appeared better trained; and the sequences they selected, as well as the content, varied greatly among students. It was reported that in no instance did a self-selected sequence parallel that of the formal course. The formal course previously taught was considered by the authors to be individualized, because the class numbered from four to eight in size; however, the first six weeks of the formal course was taught by the lecture method. It is doubtful that many people would have felt this formal course highly individualized. Presumably the large reduction in time for the self-sequenced group was due to not having to cover material already learned. The Ss were engineers and supposedly had varied entering behaviors and knowledge. The question remains regarding how to account for the subjective rating of the manager that the self-selected sequence group was superior. Was this group better trained, or could they have instead been more eager and interested?

Mager & Clark (1963) reported a study (Allen & McDonald, 1963) which taught the pieces, rules and strategies of a game by two methods. One method was a linear program while another group was given a list of the objectives and told they could ask any questions that they wished of the instructor. Although the inquiry group followed no obviously systematic sequence, the terminal performance was almost as good as the linearly sequenced group with the additional advantage that learning occurred in half the time that it took the linearly sequenced group. It was not clear whether this task could be considered to have an ordered structure and no statistics were reported by Mager & Clark.

Cambell & Chapman (1967) reported a fairly comprehensive study using 218 Ss in the fourth and fifth grades for a period of one full school year. Learner control and program control of instruction were used as the two experimental conditions. Both groups were shown the structural relations and given the specific objectives as well as being provided with feedback from both program responses and practice problems for evaluation of their own performance. Self-initiated review was allowed. Test performance throughout the eight month course, as well as on a retention test given five months later, showed no group difference. The objectives were stated as principles rather than performances and short programmed segments as well as film strips were used as instructional materials. The nine main units were taken one at a time in sequence, and although 70 percent to 80 percent of the class time was used for the individualized learning experiences, the remaining time was used in group discussions. It should also be mentioned that the subject matter was geography, and might not be considered as structurally ordered as science or math. It was found that relative to the program control group the learner control group had a significantly increasing trend in performance over the units. The program control group also did more out of class work during the first half of the course; although, the magnitude of this extra work could not be assessed. The extra work might be reflected in an efficiency measure yielding more efficient learning for the learner control group, since there was no significant difference in terminal performance or retention. A self-report questionnaire was administered, and it was found that the learner control group gained significantly more in interest in learning about geography and preference for directing one's own learning experiences.

Consideration of Individual Differences

To consider an individual as a unit distinghishable from a group of learners one must have means of distinguishing among learners. A dimension which has shown some validity in discriminating among individuals in their learning ability has been the area of cognitive ability.

Ferguson (1954) was one of the early investigators who gave the rationale for the use of abilities in learning. Abilities, which can be considered generalized skills, could have an effect on performance in a learning task by means of transfer. If a certain ability were called upon in a task, then *Ss* which had different levels of this ability should perform differentially in the task.

Games (1962) used a rational approach to determine the role of two memory abilities in learning a number of verbal tasks. Rather than having factor analyzed the learning scores and the six tests used to mark the two memory factors together, Games used factor analysis techinques on the six marker tests to get a two factor space then projected the learning measures into this factor space. By using a factor extension procedure, Games was able to concentrate on the relationship of his learning measure to the factorially defined abilities.

Bunderson (1967) used a quantative approach similar to that of Games, but an analysis of the roles of abilities was based on a considerably different rationalle. From an information-processing model, three higher-order processes were postulated and certain ability measures deemed important to these processes were selected. Support was given to the information-processing model by the differential relationship of the abilities at different stages of practice in the learning task.

Dunham & Bunderson (1969) have shown the effect of an instructional variable on the relationship of cognitive abilities to performance in a concept learning task. One group was given the rules necessary to classify correctly the stimuli while another was not. Each group was divided into solvers and nonsolvers, and a discriminant analysis for the solvers was computed using the factors found from administration of a test battery of ability measures. It was found that Ss with a particular ability were successful under one instructional condition, and Ss with a different ability were successful under another condition.

The implications of the study by Dunham & Bunderson (1969) are of particular interest. If it were agreed that it were desirable to maximize performance on a set of criteria, then the most efficient way to achieve this goal may be to give instruction appropriate to the ability profile of an individual. It has not been implied that a person's ability structure could not be changed or that it might not be fruitful to enhance some abilities. Nothing was implied other than that perhaps the most rapid means of attaining the desired criteria was to tailor the instruction to the individual based upon his particular set of generalized skills or abilities.

Predictive power was gained by hypothesizing a set of abilities important in a task or given treatment. The set of abilities was derived by an analysis of the cognitive processing required. Dunham & Bunderson (1969) discriminated groups on the basis of the factorial ability measures while Wodtke et al. (1968) who used the Scholastic Aptitude Test obtained no such discrimination.

The nature of relationships between the cognitive abilities and variations in learning task structure has not yet been shown. There has been some indication of a performance increase when the task structure and the sequence of instruction were similar. The current study was in part an attempt to synthesize the available information and clarify the relationships among the three areas.

The Interrelationships

The relationship between task structure and instructional sequence was not clarified by the literature search. It has been shown that there are various ways of assigning a structure to the learning task. The lack of a relationship between the assigned task structure and instructional sequence, in terms of the learner's performance, could be due to the method of determining the task structure. If the instructional sequence were unrelated to learning performance then one would not expect to find some sequences improving a group's mean performance, but a few studies have indicated a performance increase for certain sequences and tasks.

Another possible explanation exists to account for the inconsistent findings of studies investigating instructional sequence. If an instructional sequence were best determined idiosyncratically, as was done in the self-selected sequence studies, then a relationship between task structure and instructional sequence would not always appear.

Structural analysis. At first the Gagné method appeared to be superior to the other methods for determining the task structure, since it was more objective and had received some empirical support. However, when the Gagné analysis was used by this author and others at The University of Texas, low interjudge reliability of structure determination resulted. The experience gained in trying to perform a task analysis which used the Gagné method led this author to look for a more reliable method than an analysis of the "learning hierarchy". This low interjudge reliability of structure determination may have occured since the skills to be learned were restricted to two of the highest levels in the Gagné hierarchy, concept & principles. Gagné has not suggested any analytic procedures to work within a given level of his hierarchy. Recently Gagné (1968b) recommended that an empirical determination of the sequence be made. He implied that no general rational approach which assumes that the resulting structure represents positive transfer relationships can be used to determine sequence. The effect of this empirical approach would be to greatly lengthen the time necessary to develop an instructional sequence, and often make it infeasible.

The following method was defined as an attempt to determine the structure of a task which would be objective and would lead to an ordering of steps which would be reproducable reliably.

If one starts with the terminal objective and asks what is the first processing step that should be performed to achieve the terminal objective, then asks what are the succeeding steps one at a time, one can derive a flow of information processing that must occur to reach the terminal objective. This analysis takes a highly specific terminal objective and breaks it down into a set of processing steps which are ordered by inputs and outputs. Process step "x" would be ordered before process step "y" if the output of step "x" were required as input to step "y".

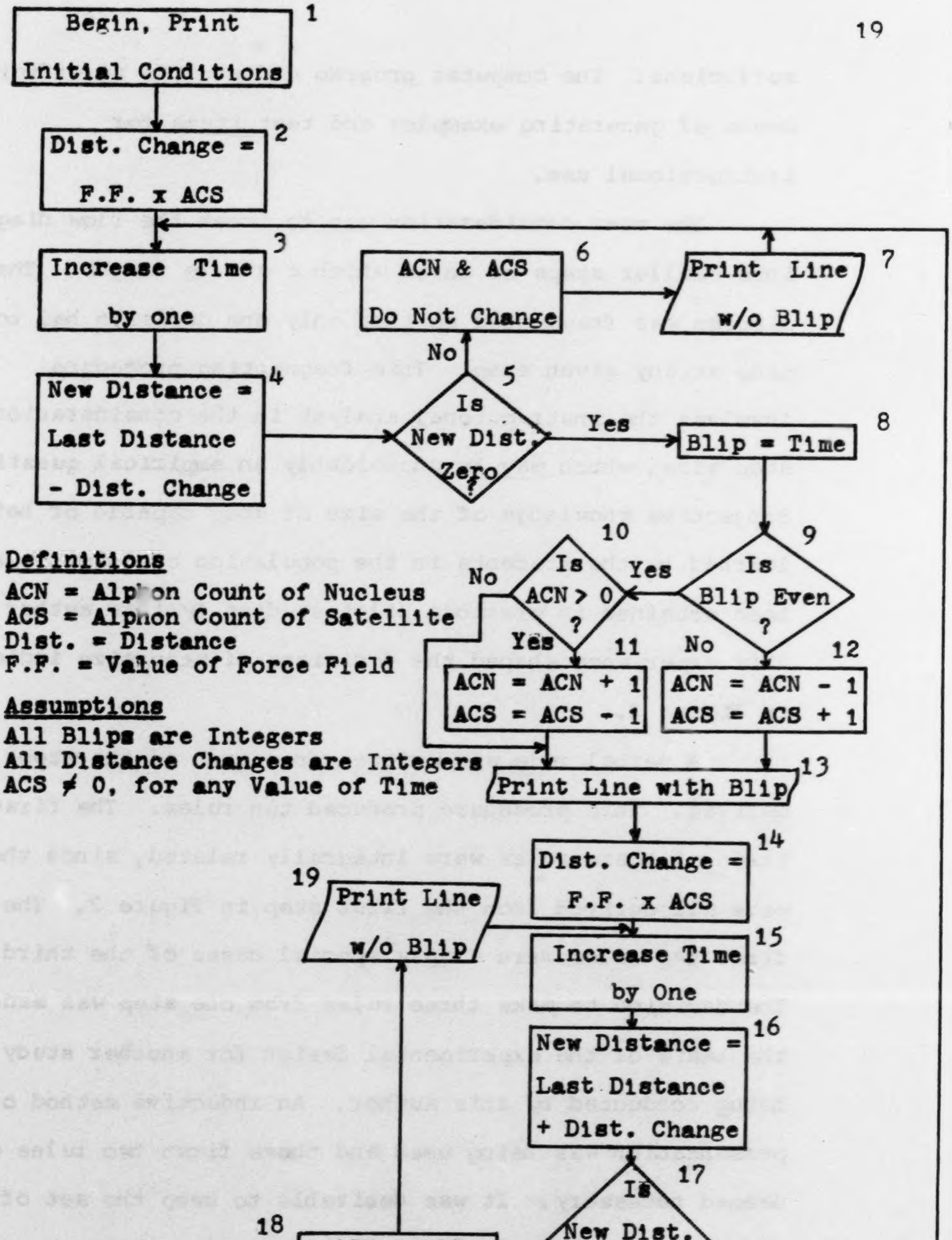
The clearest way to demonstrate this procedure is to apply it to a well defined task.

The task used in this study was considered to be the learning of an algorithm, because rules of computation were learned. The terminal objective for the student was the same objective used by Merrill (1965) and is described later. To achieve this objective, S needed to use different computational rules in a specific sequence.

An imaginary science. The imaginary science called the Science of Xenograde Systems (Merrill, 1965) was chosen for this study. The science can be used in research to bridge basic learning research on one side and curriculum development on the other. The science has the properties of both being somewhat meaningful while having good experimental control.

For years researchers investigating verbal learning have used nonsense syllables for research. This artificial science material has been used to prevent experimental contamination from Ss prior experience with the materials. It was hoped that this imaginary science task would serve the educational researcher interested in concepts, principles, and problem solving in much the same manner that the nonsense syllable task has served the verbal learning researcher. In addition, learning sets and different abilities may exert their effects uncontaminated by prior task knowledge. It was extremely unlikely that S would already have knowledge of any of the course content. Making the assumption of no prior knowledge by S allows an experimenter to bypass the pretesting of the science and represents a saving in time. Assuming no prior knowledge by S also preserves the quantity of available Ss, since none have to be discarded because of prior familiarity with the content.

The newly defined procedure of information-processing analysis was followed to produce a flow diagram of the Xenograde Science as shown in Figure 1. Figure 1 represents a final version; the first attempt produced a less efficient algorithm. The process used to achieve this final diagram was an iterative one with several revisions before arriving at the end result. There might be a more efficient algorithm than the one in Figure 1, but this one appeared good. The next step was to program the algorithm in the Fortran IV programming language. To test the rationality of the flow diagram the program was executed by a computer. The resulting output was checked for many different initial conditions and the program consistently produced the correct results. Support thus was provided for the validity of the algorithm. The computer program was not a necessary step in testing the rationality of the diagram. A careful testing of the diagram by using different initial conditions and stepping through the diagram performing the indicated procedures would have been


1
Begin, Print
Initial Conditions
2
Dist. Change =
F.F. x ACS
3
Increase Time
by one
4
New Distance =
Last Distance
- Dist. Change
5
Is
New Dist.
Zero
?
No
Yes
6
ACN & ACS
Do Not Change
7
Print Line
w/o Blip
8
Blip = Time
9
Is
Blip Even
?
Yes
No
10
Is
ACN > 0
?
No
Yes
11
ACN = ACN + 1
ACS = ACS - 1
12
ACN = ACN - 1
ACS = ACS + 1
13
Print Line with Blip
14
Dist. Change =
F.F. x ACS
15
Increase Time
by One
16
New Distance =
Last Distance
+ Dist. Change
17
Is
New Dist.
Same as Orig.
Distance
?
Yes
No
18
ACN & ACS
Do Not Change
19
Print Line
w/o Blip

Definitions
ACN = Alphon Count of Nucleus
ACS = Alphon Count of Satellite
Dist. = Distance
F.F. = Value of Force Field

Assumptions
All Blips are Integers
All Distance Changes are Integers
ACS ≠ 0, for any Value of Time

Figure 1. Information processing flow

sufficient. The computer program did provide an efficient means of generating examples and test items for instructional use.

The next consideration was to break the flow diagram into smaller steps or units which could be taught. The diagram was fragmented so that only one decision had to be made at any given step. This fragmenting procedure involves the instructional analyst in the consideration of step size, which may be unavoidably an empirical question. Subjective knowledge of the size of step capable of being learned by the students in the population of interest had been obtained in previous pilot studies by this author. This experience shaped the decisions of step size indicated in Figure 2.

A verbal rule was written from each of the steps thus derived. This procedure produced ten rules. The first three of these rules were integrally related, since they were all derived from the first step in Figure 2. The first two rules were simply special cases of the third. The decision to make three rules from one step was made on the basis of the experimental design for another study being conducted by this author. An inductive method of presentation was being used and these first two rules were deemed necessary. It was desirable to keep the set of materials the same in both studies so some cross comparisons could be made.

Other methods for determining the structure of a task

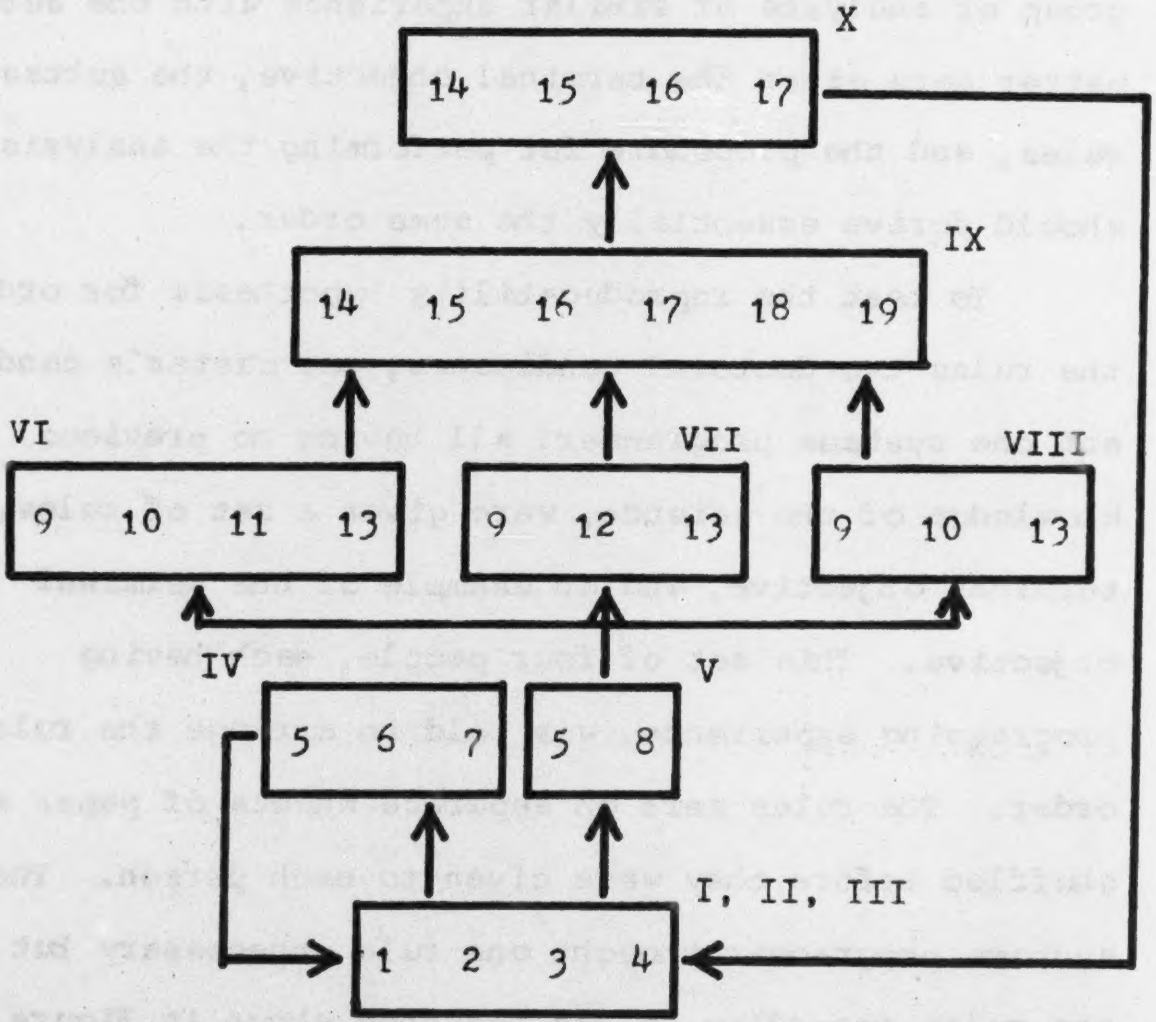

X
14 15 16 17
IX
14 15 16 17 18 19
VI
9 10 11 13
VII
9 12 13
VIII
9 10 13
IV
5 6 7
V
5 8
I, II, III
1 2 3 4

Figure 2, Size of step (arabic numerals are the same as those in Figure 1, the roman numerals indicate verbal rules).

did not seem to have the characteristic of reproducability of ordering the subtasks once they were defined. The information-processing analysis takes a subject matter expert, but it is thought to be an objective method. If a group of analysts of similar experience with the subject matter were given the terminal objective, the subtasks or rules, and the procedure for performing the analysis they should derive essentially the same order.

To test the reproducability hypothesis for ordering the rules two doctoral candidates, one master's candidate, and one systems programmer, all having no previous knowledge of the science, were given a set of rules, the terminal objective, and an example of the terminal objective. This set of four people, each having programming experience, was told to arrange the rules in order. The rules were on separate sheets of paper and shuffled before they were given to each person. The systems programmer thought one rule unnecessary but ordered the rules according to the sequence shown in Figure 1. The others ordered them in this same order. One of the individuals completed the task in fifteen minutes. This method of structure determination thus seemed to have the desired property of reproducing the ordering of steps which the other method of analysis lacked. A validation of this analysis was the next consideration, since a satisfactory procedure for the information-processing analysis was attained. To determine if this structural analysis yielded some instructional benefit, it was necessary to quantify the degree of proximity to or departure from this sequence.

Quantification of instructional sequence - the HSCI. It seemed reasonable to assume that there were measurably different sequences of presentation which ranged from strict adherance to the task structure to a completely reversed sequence. An index which would specify the degree of conformity of a presentation to the task structure was strongly indicated.

It should be remembered that one result of an information-processing task analysis is a flow diagram which consists of the processing diagrammed as nodes and lines which show the interconnection of the nodes. The lower level nodes are inputs, which implies their being prerequisite, to the higher level nodes into which they are connected. A given subject matter may be composed of a number of these prerequisite units interconnected in various ways.

A unit in the hierarchy could be specified as a terminal node and all of the independent nodes which immediately preceded. It is the assembly of these units upon which the hierarchial sequence conformity index (HSCI) is based. Figure 3 shows the formula for determining the HSCI.

The HSCI would have a value of $\overline{W}$ (the mean weight) if all prerequisites in a hierarchy were attained prior to

$$HSCI = \frac{\displaystyle\sum_{n=1}^{N} \frac{\displaystyle\sum_{i=1}^{K} Wpn_i}{\text{Number of prerequisite nodes required before a terminal node}}}{N}$$

Where N = the number of prerequisite units in the task,
Wpn_i = the weight of any given prerequisite node,
and K = the number of prerequisite nodes actually attained before a terminal node.

Figure 3. The HSCI formula.

attempting a higher level. $\bar{W}$ would be 1.00 if all weights were 1.00, as they were assumed to be in this study. The HSCI would have a value of 0.00 if no prerequisites in a hierarchy were attained prior to attempting a higher level. For HSCI = 0.00 it would be necessary for the sequence of instruction to progress in a reverse hierarchial order. This reverse order is the only sequence that would yield a value of zero. Therefore, HSCI ranges from zero to unity. Intermediate values for the HSCI would be attained by various degrees of nonconformity to a hierarchial presentation.

At the present state of knowledge, an assumption of equal weight for all contributing prerequisite nodes within a prerequisite unit must be made. The index gives less weight to any single prerequisite node when the number of prerequisite nodes in a prerequisite unit increases.

There is no way of telling whether or not the task used in this study did violence to the assumption of equal weight without obtaining extensive difficulty statistics for each node and transfer statistics between nodes.

The units for the task are shown in the abbreviated schematic task diagram in Figure 4.

Whether the assumptions underlying the index are completely valid or not, the HSCI is a way of quantifying the degree of hierarchial presentation of a task. The HSCI does not define the hierarchy; however it gives an ordinal measure of the degree to which this hierarchy has been

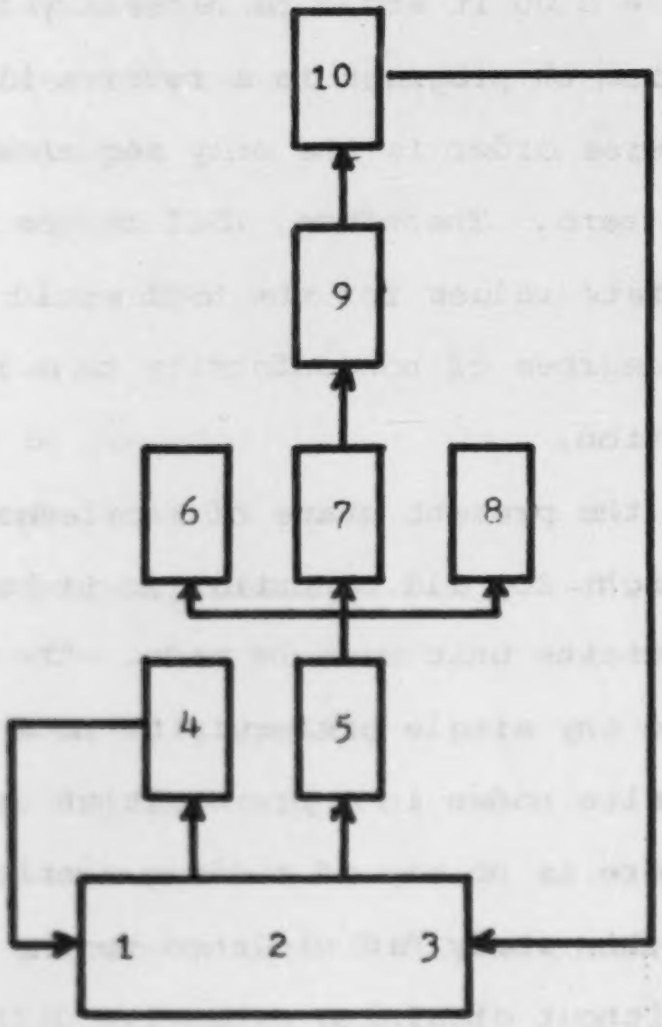

10
9
6
7
8
4
5
1
2
3

Figure 4. Diagram of the hierarchy of skills (rules) for the Xenograde Science (lowest level at bottom).

followed. The validity of the index as a meaningful index of systematic variation in sequencing was supported by pilot research. A pilot study demonstrated that the HSCI was linearly related to terminal performance for values of the HSCI from 0.50 to 1.00 under program control.

Structure, sequence, and ability. The only study to mention a possible relationship between cognitive individual differences and instructional sequence was Payne & Krathwohl (1967). Associative Memory and Induction were hypothesized as assisting performance when a task was presented out of sequence.

Terminal performance in this task required the ordered application of the different rules. If the rules were not learned in order then one might have to induce the order to have the necessary inputs for each step to proceed efficiently through the task.

The analysis of cognitive processing required in the task did not yield any specific relationship between instructional sequence and Associative Memory. A measure of Associative Memory was included because of the suggestion of Payne & Krathwohl (1967), and because Associative Memory and Induction were found to interact in an unpublished pilot study for another experiment conducted by this author.

A General Reasoning ability measure was also included for exploratory purposes. This ability may be thought of as an organizing ability and could have relevance in selecting one's own sequence.

Results of a Pilot Study

A pilot study using the imaginary science materials was conducted to investigate the relationships of different assigned and self-selected sequences and the relationships of abilities. Sufficient data to indicate relationships was obtained only over the range 0.50 - 1.00 for the HSCI. A definite postive linear trend was obtained between performance and instructional sequence as quantified by the HSCI. There was an apparent disordinal interaction between a self-selected and an assigned sequence. The performance of the self-selected sequence group increased as the HSCI approached 0.50 from 1.00 while the performance of the assigned sequence group decreased. The cognitive ability of Induction interacted ordinally with the assigned sequences. Low levels of the Induction ability produced larger decrements in performance, as the HSCI decreased from 1.00 to 0.50, than high levels of Induction.

Four classes of questions are implied by these results. The first question is concerned with the effects of departures from a hierarchical presentation sequence when students are assigned sequences. The second question is concerned with the relationship of abilities to performance with assigned sequences and the interactions of abilities and performance with the HSCI. A third question is concerned with the comparison of self-selected and assigned sequence and the interaction with different sequences. The fourth question is more exploratory and includes the prediction that General Reasoning will be positively related to self-selection because of its organizing implication. Exploratory aspects of the study also include an examination of group and ability effects on a wide range of dependent measures.

Statement of Hypotheses

To address the questions of the role of instructional sequence and its relationship to individual differences the following conditional hypotheses were made. Because of the complexity of this study, bringing together as it does questions from aptitude by treatment research, task analysis, and instructional sequencing, the exploratory research opportunities were perhaps equally important.

Hypothesis 1. If departures from program-controlled hierarchical presentation hiner learning, then:

A) significantly more errors will occur for students learning from nonhierarchical sequences than from hierarchical sequences.

B) students in non-hierarchical presentations will take significantly more time to learn than students learning from hierarchical presentations.

Hypothesis 2. If #1 is true, and HSCI is a valid indicator, then an inverse relationship will exist between HSCI and errors and/or HSCI and time to learn. In addition, there should exist a positive relationship between HSCI and attitude scores. That is, as HSCI approaches zero, errors and/or time should increase and attitude ratings should decrease.

Hypothesis 3. If HSCI is a valid indicator of conformance or departure from a hierarchical sequence as indicated by the tests above, then as HSCI decreases, the relationship of the abilities of Induction and Associative Memory to performance should increase.

Hypothesis 4. There may be intrinsic advantages in motivation and meaningfulness for learning sequences selected by the student, rather than forced by the program, which will lead to better performance. This leads to the predictions that:

A) mean performance for group SS on the post-test will be superior to that of group Y.

B) group SS will be negatively related while group Y will be positively related to performance over the range of the HSCI (0.50 - 1.00) reported in the pilot study. These relationships will be manifested on posttest scores, retention scores, transfer scores, and attitude scores.

Hypothesis 5. There will be a significant positive relationship to performance in group SS of General Reasoning ability.

CHAPTER 2

METHOD

Subjects

Students in five self-paced introductory psychology classes for secondary school teachers were required to participate. A total of 176 *S*s were initially tested and a total of 164 *S*s completed the experiment. Several *S*s had to be discarded because of computer malfunctions and several because of illness. Some of the retention test, transfer test, and attitude questionnaire data was lost due to oversight on the part of proctors assisting the experimenter.

Ability Measures

French, Ekstrom, & Price (1963) have published a kit of tests to be used in factor analytic research. Tests to mark the abilities of interest in this study were selected from the kit. Associative Memory was marked by the *Object-Number Test* and by the *First and Last Names Test*. Induction was marked by the *Letter Sets Test* and by the *Locations Test*. General Reasoning was marked by the *Ship Destination Test*, the *Necessary Arithmetic Operations Test*, and the *Mathematics Aptitude Test*.

The Memory factor has consistently and clearly been defined as a construct by the two indicated tests. The tests used to mark Induction require that *S* induce a rule given several instances. The tests could be considered a form of concept learning. The *S* is provided with several instances and must induce a rule to classify correctly another instance. The three tests to mark General Reasoning were included for exploratory purposes.

As French et al. (1963, p.2) stated "It may be expected that the use of these tests will ordinarily cause the named factors to appear. However, particular conditions of the testing or of the analysis may sometimes prevent a factor from separating as expected."

To obtain the predicted factors from the test battery, it was decided to use a principal axis factor analysis followed by a varimax rotation. A computer program for performing the factor analysis written by Veldman (1967) and coded in Fortran IV was used in this study.

Experimental Task

Merrill (1965) developed a complex imaginary science for learning research called the Science of Xenograde Systems. The ideas for the science were originated by Carl Bereiter for studying group interaction problems at the Training Research Laboratory, University of Illinois. Merrill's version of the science contains three satellites which revolve about a nucleus containing particles called alphons. The laws and relationships among the various components of the system comprise the subject matter of the science. Since the task is imaginary, it is most unlikely for any S to have prior knowledge of the content, and yet the structure of the science is similar to topics covered in science courses.

A simulation program for the IBM 1500/1800 Instructional System was developed at the Computer-Assisted Instruction Laboratory, The University of Texas, by this author and Paul Merrill under the direction of C. Victor Bunderson. In a series of pilot studies the science was found to be very difficult for Ss to learn. This study used a highly modified version of the science which simplified the content such that learning of the entire science occurred in one hour or less, rather than the four hours needed for earlier versions of the science. This last version also used the information-processing analysis described in the preceding chapter. Appendix A lists the concepts, rules, and a statement of the terminal objective covered by the modified version of the science. This modification was planned for pragmatic reasons. It was difficult to find Ss willing to participate in a study which required eight hours of their time. The modification decreased the time involved in learning the task, while keeping the ordered structure and other advantages desired for the experimental task.

Instructional Equipment

Instruction was administered by the IBM 1500/1800 Instructional System. Use of this computer-based instructional system does not tie the course designer to any particular pedagogy. The computer system facilitated the collection of time and error measures as well as making recordings of the student's actual performance. The program used in this study was written in the Coursewriter II language. Presentation of materials was by means of a cathode ray tube display, a computer-controlled image projector, and by mimeographed handouts. Student responses were entered by means of a keyboard at the computer terminal. Other responses were recorded on mimeographed forms with pencil.

Design

A pilot study using a design similar to the present one with 49 students from introductory psychology courses indicated that the HSCI might be a valid index related to performance and that the other questions were worth pursuing. Support for the validity of the HSCI in the pilot study came from a linear trend for the HSCI to be positively related to performance over the range (0.50 - 1.00) of the HSCI values sampled when sequence was under program control.

In the current study one group called the self-selected (SS) group was used which allowed S to choose his own sequence of rules. The S was also allowed to repeat individual rules; although with each repetition the example was different. Two related representations of the structure of the imaginary science were provided S. A flow diagram of the task and a list of the behavioral objectives of each of the ten "lessons" (rules) served as the two representations. For comparson another group was yoked S for S to group SS. This yoked (Y) group was not provided with the representations of the task. A member of group Y was given the sequence determined by the subject to which he was randomly matched. He received the same number of examples on each rule in the same order as his randomly paired S in group SS had chosen. It was expected that uneven distributions of Ss classified by HSCI would result for group SS and thus for group Y. Although the availability of a task representation was not thought to be a major variable affecting performance in group Y, two other groups were included to confirm this assumption. These two forced sequence (F) groups were included to determine the effect of the representations on performance when the sequence of instruction was previously determined and no repetitions of any rule were allowed. Equal distributions of Ss classified by HSCI were established for the two F groups. If no difference was detected between the two F groups then the effect of the representation could be considered nill and the two F groups at each level of the HSCI for a predetermined sequence could be combined. The combined F group with group Y then would be compared to group SS to determine the relative effects of self-selection and program control of sequence.

The posttest designed to test the terminal objective was given on the computer. The terminal objective is: given the initial conditions of ACN, ACS, Distance, and Force Field (F F), the student will be able to produce a complete table of Xenograde readings line by line from time zero up to any specified time. Each successive line in a Xenograde table requires information from the preceeding line. Because of this, correct scoring required a preceeding line to be correct or the following line would also be in error. Thus, student errors were scored by the computer program and corrected immediately. This in effect resulted in a correction procedure which could introduce learning into the posttest measurement situation. A control (C) group was necessary to assess the effect of the correction procedure. One group was assigned the task of taking the posttest without any instruction, except how to operate the computer terminal. It was assumed that learning in group C would be due to the corrective feedback following errors. The mean score for this group was used as a base level of performance on the posttest.

Table 1 is a summary of the experimental design showing the differences and similarities of treatment among the groups during the learning phase.

Linear regression analysis and analysis of variance techniques were used to test hypotheses related to abilities and the instructional sequence respectively. Contained in Appendix C is the detailed description of the regression restrictions and models which were employed.

Dependent Measures

Various indices of performance were taken. These included a posttest, retention test taken two weeks after

Table 1

Summary of the Experimental Design

Group	Number of times a rule could be taken	Structural Representation Available?	Predetermined Sequence?
Self-selected (SS)	n*	yes	no
Yoked (Y)	n*	no	yes
Forced without representation (F$\overline{R}$)	1	no	yes
Forced with representation (FR)	1	yes	yes
Control (C)	0	no	--

*Subjects in group SS may repeat any given rule n times, where 1 n 5. The subject randomly matched to a S in group SS received the corresponding rule the same number of times.

the posttest, and a transfer test taken after the retention test. Examples of both forms of the posttest-retention test with answers, transfer test with answers, and the attitude questionnaire are included in Appendix B. A diagram showing the rule(s) which were applied to obtaining each answer in the posttest and retention test is also given in Appendix B.

Time to learn the science. The length of time from presentation of the first rule until the student completed the instruction was accumulated. This measure indicated the total time spent by the student in studying all rules and completing the three test questions which followed presentation of each rule and example.

Posttest - retention test. The test of the terminal objective (posttest or retention test) contained either 132 or 144 items. Since the test had to be given twice to each *S*, two forms were desired. No statistics were available as to whether the tests were parallel or not; therefore half of each group received one form and one-half the other form for the posttest. To measure retention *S* completed the form which he had not previously taken. The tests were constructed so that the same behavior was measured with comparative freqency by both forms.

The test required *S* to fill in each entry in a table, line by line by keying entries which appeared in context in the table on a cathode ray tube. After completing a line *S* was informed of his incorrect responses, and the correct answer replaced any incorrect ones. No specific feedback action was taken if S's answer was correct. As soon as S completed the test he was told how many items he had answered correctly. This total score was converted to percent correct and used for the primary analysis as a measure of overall proficiency for the posttest and as the only criterion for retention. The conversion to percent correct allowed the two alternate forms of the test to be compared since there was a small difference in the total number of items between the two forms.

Knowledge of rules three through ten of the science materials were assessed by the posttest-retention test; although each rule was not measured with equal frequency. The total percent correct score thus gave greater weight to comprehension of some rules which had to be used most frequently. Because of the unequal numbers of items to measure comprehension of individual rules on the posttest the number of errors on a rule was weighted according to the total number of items to give equal weight to each rule in determining a measure of overall posttest proficiency. Table 2 gives the item weight of each of rules three through ten for both forms. No items measured comprehension of rules one and two (special cases of rule three). This weighting scheme also deemphasized the learning effects caused by the feedback procedure of the test by giving more weight to items where learning was less likely to occur from the feedback procedure.

Table 2

Adjusted Weight* for Total Errors by Test Form for the Posttest & Retention Test

	Form A	Form B
Rule 3	.810	.810
Rule 4	.470	.475
Rule 5	.960	.955
Rule 6	.965	.965
Rule 7	.965	.965
Rule 8	.980	.980
Rule 9	.880	.880
Rule 10	.970	.970

$$^{*}\text{Adjusted Weight} = \frac{\text{total possible errors this form} - \text{total possible errors this rule}}{\text{total possible errors this form}}$$

A measure of the comprehension of each of the rules given in "lessons" three through ten was assessed by accumulating the number of errors made on posttest items corresponding to each rule. No adjustment was made to these scores since it was a rule by rule comparison and the number of items to measure a given rule was essentially the same on both forms, as shown by comparing item weights from Table 2.

Transfer test. The transfer test required S to infer three new rules of the science given two example tables. The subject then completed nine test items of the same format as was used for test questions during the science instruction. Fifteen minutes was allowed for this task, and the total number correct was used as the dependent measure.

Attitude questionnaire. The attitude questionnaire was a checklist consisting of ten items. Ten statements related to the task were given and S had to mark a four choice scale ranging from "strongly agree" to "strongly disagree" each of the choices was ranked on a scale from one to four. A value of one indicated an unfavorable attitude toward the experiment while a value of four indicated a highly favorable attitide. An eleventh item allowed S to write in that aspect which he most and least liked. Scores for each of the ten statements were used as dependent measures.

Procedure

During five two-hour sessions large groups of Ss received a thirty minute lecture presentation by E. The lecture covered an introduction to CAI, ability by treatment interaction studies, and the value of their participation in this study. These presentations were given in order to develop Ss interest in the study. Each S elected which one of the five sessions he wanted to attend.

Immediately following the lecture, Ss were tested on selected cognitive abilities. Seven tests from the battery (French et al., 1963) were used to mark the factors of Associative Memory, Induction, and General Reasoning. The first test given was the Necessary Arithmetic Operations Test followed by the First and Last Names Test, the Locations Test, the Ship Destination Test, the Object-Number Test, the Letter Sets Test, and the Mathematics Aptitude Test.

Following the testing Ss were told to make individual appointments at the Computer-Assisted Instruction Laboratory. Each S scheduled two appointments with a two week interval between appointments.

At the first session in the lab, S was first given an introductory course administered by the computer which taught terminal operating conventions and procedures. It was hoped that the introductory course helped to desensitize S to the terminal and CAI before instruction began.

After S had completed the introductory course, he was given a booklet to read. This booklet gave an introduction to the Xenograde science, the justification for learning the science, some humorous background material, instruction for reading the computer terminal data displays, and group specific procedures. In Appendix D is found a sample booklet for Ss in the self-selected sequence group.

As soon as S finished reading the booklet, he took the CAI program to learn the science. The science consisted of ten rules each of which had five examples available. Three constructed response test items for each example were also available in the instructional program.

If S were in groups Y or F he was assigned a sequence of instruction by a proctor at the beginning of the computer-administered course. This sequence was keyed into the computer by the proctor, and the computer then determined the next "lesson" from the stored list. Some reminders as to how to operate the terminal were presented S first, and when he had read them the first "lesson" was presented. Each "lesson" consisted of one rule, an example, and three test items. Simultaneously presented with each rule was a unique example. When S believed that he understood the rule, he indicated that he was ready for a test of the rule by typing the word "test" at the terminal keyboard. The subject was then required to type a numeral to fill in a missing piece of data on a display.

The item required the use of the rule to obtain the correct answer. Following three such test items, S was informed of how many items he had answered correctly; although he was not given the correct answers. The next rule was then presented and S went through the same procedure. The subjects in one of the F groups (FR) were given the two representations, a flow diagram of the task structure and a list of behavioral objectives, and told to study them carefully before each rule-example presentation. As soon as the last rule was completed S was told that he had completed the task and was ready for the posttest. The first lab session was completed as soon as S completed the computer-admisistered posttest.

Two weeks after the first lab session S returned and took the alternate form of the computer-administered test (retention test). After completing the retention test S was given the mimeographed transfer test. A mimeographed attitude questionnaire was then given to each S.

At the beginning of the learning session Ss in group SS were shown a diagram of the hierarchy as shown in Figure 4. The behavioral objectives in their booklet (Appendix D) corresponded to this diagram. After studying both representations S selected the lesson that he wanted to take by typing in a letter corresponding to the desired lesson at the keyboard. The rule and corresponding example were then presented. Following observation of this rule and example, S typed the word "test" and then completed the three test items. After having been informed how many items he answered correctly S was returned to the diagram of the hierarchy to select the next lesson. If S selected the same rule again, he was given the same rule but a new example and different test items. His selection of the sequence of instruction continued until he indicated that he had taken at least one example of each rule and had done enough work to take the criterion test. If S chose to repeat a rule after all five examples had been taken, he was informed that there were no more examples and he was returned to the diagram of the hierarchy. When S had taken at least one example of each rule he was allowed to terminate instruction. The remaining tests and attitude questionnaire for group SS were the same as for the other groups.

While taking the course, Ss were not allowed to have any paper or pencils with them. Subjects were also asked to refrain from discussing the particulars of the course with others who were yet to take the course.

CHAPTER 3

RESULTS

Because of the complexity of the research design there was no simple test of each hypothesis. A difference between groups may in some cases have been due to several confounding factors. Each of the different dimensions along which groups varied (see Table 1) needed to be tested to eliminate alternate explanations of any obtained group differences.

The primary performance criterion of interest was the total percent correct on the posttest. The total weighted errors on the posttest (Table 2) was found to correlate highly ($\underline{r}$ = -0.97) with the total percent correct on the posttest as would be expected. The other criteria, not specified explicitly by a hypothesis, were included for exploratory purposes and reported under the heading Exploratory Results.

Test of Hypothesis 1

A test of this hypothesis was made first by testing for criterion variance attributable to variation in the HSCI. Only the groups having a preselected sequence (FR, F$\bar{R}$, or Y) were appropriate for testing this hypothesis. Analysis of variance techinques were used with group classification (FR, F$\bar{R}$, or Y) as one factor and the HSCI index as the other factor.

The first two-way classification (2 x 5) analysis of variance was computed for the dependent variables with groups FR and F$\bar{R}$ as one factor and five levels of the HSCI as the other factor. No significant differences were found for the groups or groups x HSCI interaction. The HSCI factor yielded significant effects for total percent correct on the posttest ($\underline{F}(4/42) = 2.60$, $\underline{p} < .05$) and total weighted errors on the posttest ($\underline{F}(4/42) = 2.76$, $\underline{p} < .05$). No effect for the HSCI was found for the time to learn criterion. The findings indicate that for a predetermined sequence the hypothesis of no effect of task representation (presence or absence of behavioral objectives and a flow diagram) on performance could not be rejected. The hypothesis of no effect of level of HSCI on performance was rejected for errors, but not when the criterion was time to learn.

The second two-way classification (2 x 5) analysis of variance was computed for the dependent variables with groups F (FR and F$\bar{R}$ combined) and Y as one factor and the five levels of the HSCI as the other factor. No groups x HSCI interaction was found, but there was a significant difference between the F and Y groups in total time to learn the science ($\underline{F}(1/74) = 8.97$, $\underline{p} < .005$). The difference is not surprising since $\underline{S}$s in group F took only ten examples and $\underline{S}$s in group Y took between ten and nineteen examples with a mean of 11.4. The mean number of examples for group Y was significantly larger than the number of examples for group F ($\underline{t} = 4.85$, $\underline{df} = 51$, $\underline{p} < .001$ two-tail). Number of examples seemed to lengthen the amount of time to learn the science without significantly increasing criterion performance. The HSCI factor again yielded significant effects for the total percent correct on the posttest ($\underline{F}(4/94) = 4.25$, $\underline{p} < .005$) and total weighted errors on the posttest ($\underline{F}(4/94) = 4.26$, $\underline{p} < .005$), but no significant effects were detected for time to learn.

The significant differences found which were attributable to the level of the HSCI justified further inspection of the data. Hypothesis 1 compared a hierarchical sequence (HSCI = 1.00) to other instructional sequences. A non-hierarchical sequence, as defined by the HSCI, would be any sequence having HSCI $\neq$ 1.00.

The first set of comparisons used HSCI = 1.00 vs. HSCI $\neq$ 1.00. The combined preselected sequence groups (FR, F$\overline{R}$, and Y) showed no significant mean differences. When each of the groups (FR, F$\overline{R}$, and Y) were analyzed separately only one produced significant differences. The scores for group F$\overline{R}$ were divided into two groups according to whether they received a hierarchical instructional sequence (HSCI = 1.00) or not (HSCI $\neq$ 1.00). An unequal $\underline{n}$s test showed a significant difference for the total percent correct on the posttest ($\underline{t} = 3.30$, $\underline{df} = 24$, $\underline{p} < .01$ two-tail), and total weighted errors on the posttest ($\underline{t} = 3.29$, $\underline{df} = 24$, $\underline{p} < .01$ two-tail). No differences were found between the groups when time to learn was used as the criterion. The differences indicated higher mean performance when the HSCI was 1.00.

Although comparing hierarchical sequences to non-hierarchical sequences did not produce unambiguous effects, Figure 5 and the associated Table 3 indicate some interesting trends for groups F and Y across levels of the HSCI. Groups FR and F$\bar{R}$ were pooled to have enough Ss for comparison. The trends except for the values at the HSCI = 0.00 appeared to be as stated in Hypothesis 2.

Test of Hypothesis 2

Hypothesis 1 received enough support to warrent investigation of the second hypothesis. Tests for the difference between the means at HSCI = 1.00 and the means at the other values of the HSCI were calculated.

No comparisons between any groups for the HSCI = 1.00 and HSCI = 0.25 yielded significant results. The total percent correct on the posttest ($t = 2.72$, $df = 47$, $p < .01$) and the total weighted errors on the posttest ($t = 4.425$, $df = 32$, $p < .001$) were highly significant. The total attitude score did not reflect this significant difference. No differences in time to learn were detected.

The apparent reversal in the trend for performance to decrease as HSCI approached zero at HSCI = 0.00 for a predetermined sequence, as shown in Figure 4, was replicated by three independent groups (FR, F$\bar{R}$, and Y) and also in the pilot data for this experiment. Although testing for differences in mean performance between the

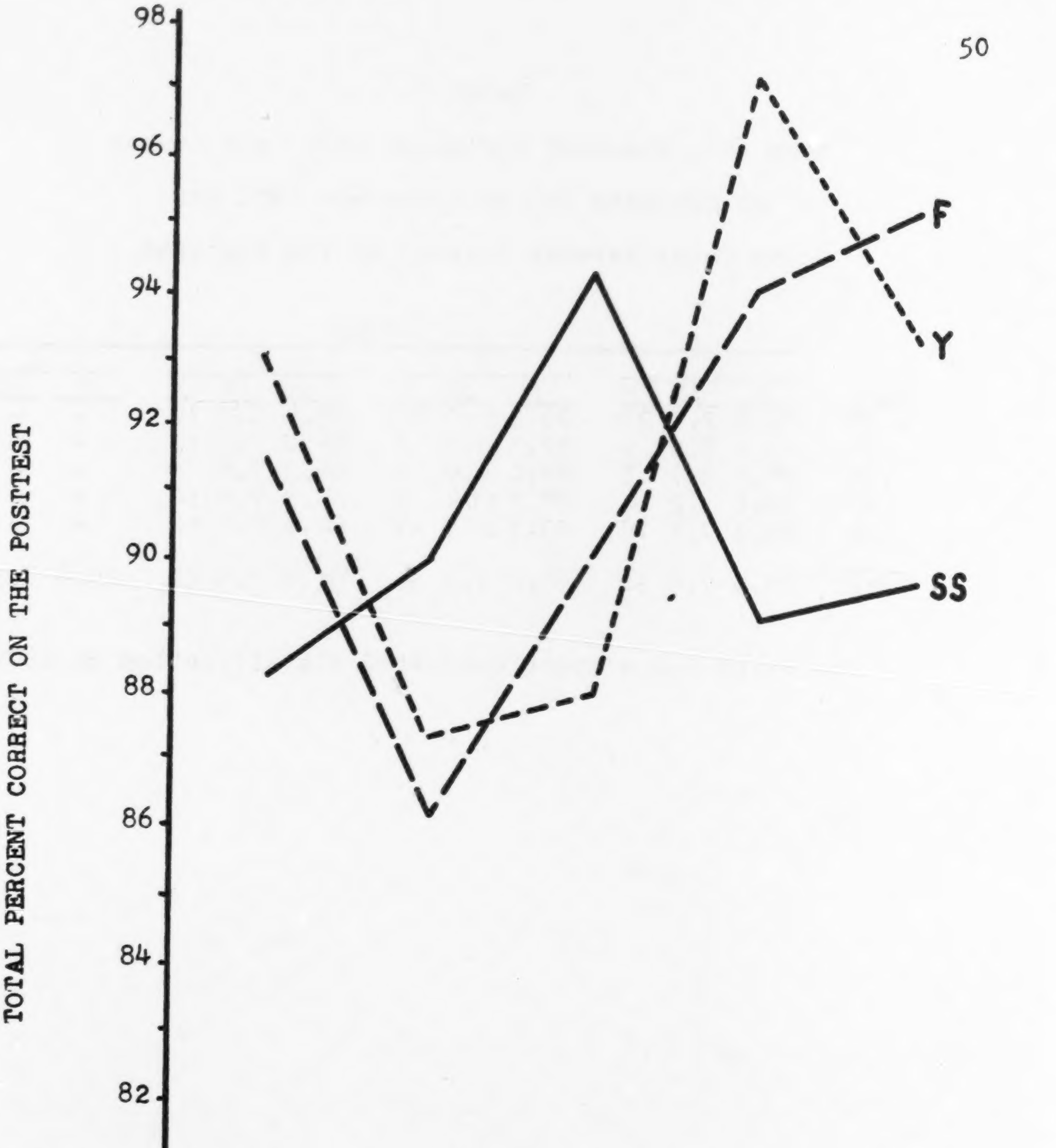


Figure 5. Group performance classified by the HSCI

Table 3

Mean (M), Standard Deviation (SD), and Number of Subjects (N) by Group and HSCI for the Total Percent Correct on the Posttest

	Group											
	SS			Y			F			C		
HSCI	M	SD	N	M	SD	N	M	SD	N	M	SD	N
1.00	89.8	7.4	25	93.3	6.9	25	95.4	5.2	10	-	-	-
.75	89.1	8.1	9	97.3	3.2	9	94.2	7.3	12	-	-	-
.50	94.4	2.7	5	88.0	6.4	5	90.3	7.6	8	-	-	-
.25	90.0	5.2	4	87.5	11.4	4	86.2	7.5	10	-	-	-
.00	88.3	9.1	9	93.1	6.0	9	91.6	6.0	12	-	-	-
Total*	89.9	7.6	52	93.0	7.3	52	91.7	7.5	52	79.4	7.5	8

*The value for a group excluding classification on HSCI

HSCI = 0.00 and HSCI = 0.25 produced no significant values, the multiple replication of this ordering of the mean values suggests a stable phenomena.

The relationship between the HSCI and the total percent correct on the posttest is also exemplified by the Pearson product moment correlation coefficient for group F ($\underline{r} = 0.30$, $\underline{df} = 50$, $\underline{p} < .05$) and group Y ($\underline{r} = 0.13$, ns).

Test of Hypothesis 3

A test of Hypothesis 3 required the application of several analytic procedures. First a factor analysis of the ability test battery was computed for purposes of construct validation.

Factor analysis of the ability tests. The major abilities of interest in this study were Induction and Associative Memory. The four tests used to mark these abilities as well as the the three tests used to mark the General Reasoning ability were subjected to a principal components analysis. These factor loadings were then rotated by a varimax procedure. The resulting varimax factor loadings are shown in Table 4. Table 4 shows a clear factor structure which yielded three factors. These factors were interpreted as being General Reasoning, Associative Memory, and Induction. Factor scores for each individual were obtained and used in the subsequent analysis of the role of abilities.

Contribution of abilities. Linear regression models (Bottenberg & Ward, 1963) were used to test questions

Table 4

Factor Matrix Loadings

TEST	REASONING	MEMORY	INDUCTION
First & Last Names	-.0476	.8728	.1827
Object-Number	.2422	.8435	-.0551
Locations	.2621	.1649	.6307
Letter Sets	.1106	-.0295	.8696
Ship Destination	.7369	.0391	.1569
Necessary Arithmetic Operations	.7350	.0835	.1876
Mathematics Aptitude	.7956	.0968	.0988

concerning the contributions of abilities to performance and the interaction of abilities with the HSCI. The analysis was performed on pooled data from all Ss having a preselected sequence of instruction. No differences were found among these groups on any criterion (except difference in time to learn the science between groups F and Y); therefore, it seemed justifiable to pool them for this analysis.

It was not feasible to include all of the ability measures and levels of HSCI in a full regression model. If a full model were constructed which had a predictor for each level of HSCI and one for each ability factor plus each combination of interaction terms the model would have 127 predictors, which would be almost as large as the number of subjects available to test the hypothesis. One way of simplifiying the model would have been to assume that HSCI had a linear relationship to performance. This linearity assumption did not seem tenable since each of the preselected sequence groups produced an apparent, but not statistically significant, minimum performance value at HSCI = 0.25 rather than at zero, which would have been expected if a linear relationship had been the true state of affairs.

Linear models were constructed using the general equation in Appendix C. For testing the hypothesis of ability by sequence (HSCI) interaction each ability measure was used separately, and tests were made to see if the regression lines of ability on the total percent correct on the posttest were parallel among the levels of the HSCI.

The measure for Associative Memory yielded a full model which predicted better than just the mean score ($\underline{F}(10/88) = 2.976$, $\underline{p} < .005$), and the equation with standard weights was as follows:

$$\text{Posttest \% Correct} = 92.08 + .14X_1 + .22X_2 - .13X_3 - .31X_4$$
$$+ .11M + .07X_1{*}M + .14X_2{*}M + 06X_3{*}M$$
$$+ .13X_4{*}M + E.$$

The corresponding $\underline{R}^2$ was 0.25.

Imposing the restriction of parallel slopes for Memory scores among HSCI levels on the criterion produced a nonsignificant difference from the full model ($\underline{F}(4/88) < 1.0$).

The other ability by instructional sequence test for hypothesis 3 was made using the Induction measure. The full model predicted the criterion score significantly better than just the mean score ($\underline{F}(10/88) = 4.070$, $\underline{p} < .0005$) The $\underline{R}^2$ for the full model was 0.32. The full model with standard weight was as follows:

$$\text{Posttest \% Correct} = 92.19 + .11X_1 + .18X_2 - .11X_3$$
$$+ .17X_4 + .13I + .01X_1{*}I - .14X_2{*}I$$
$$+ 17X_3{*}I + .25X_4{*}I + E.$$

Imposing the restriction of parallel slopes for Induction scores among HSCI levels on the criterion produced a significant difference from the full model ($\underline{F}$

(4/88) = 2.90, $p < .05$). The Induction ability was the only ability measure found to interact with the predetermined sequence of instruction as defined by the HSCI.

The specific shape of the interaction of Induction with the HSCI was demonstrated by splitting the criterion scores into two groups at each level of the HSCI. The two groups were defined by a median split on the Induction score for all Ss having a predetermined sequence. The shape of the interaction shown in Figure 6 partially agreed with the predicted effect.

The question of the "main" effect of an ability was not a meaningful question for the case of Induction. It was expected that the criterion difference between high and low levels of Induction would increase as the value of the HSCI approached zero with Ss having high Induction scores attaining higher performance. When the HSCI had the value 0.75 the obtained mean difference was in the opposite direction but nonsignificant at the HSCI = 1.00 ($t = 1.84$, $df = 11$, $p < .10$ two-tail); HSCI = 0.50 ($t = 1.84$, $df = 11$, $p < .10$ two-tail); and HSCI = 0.25 ($t = 2.18$, $df = 10$, $p < .10$ two-tail).

It had been expected that the criterion difference between Induction scores would be near zero at the HSCI = 1.00 and greatest at the HSCI = 0.00. It had been expected that the most hierarchical presentation (HSCI = 1.00) would reduce the reliance on the Induction ability.

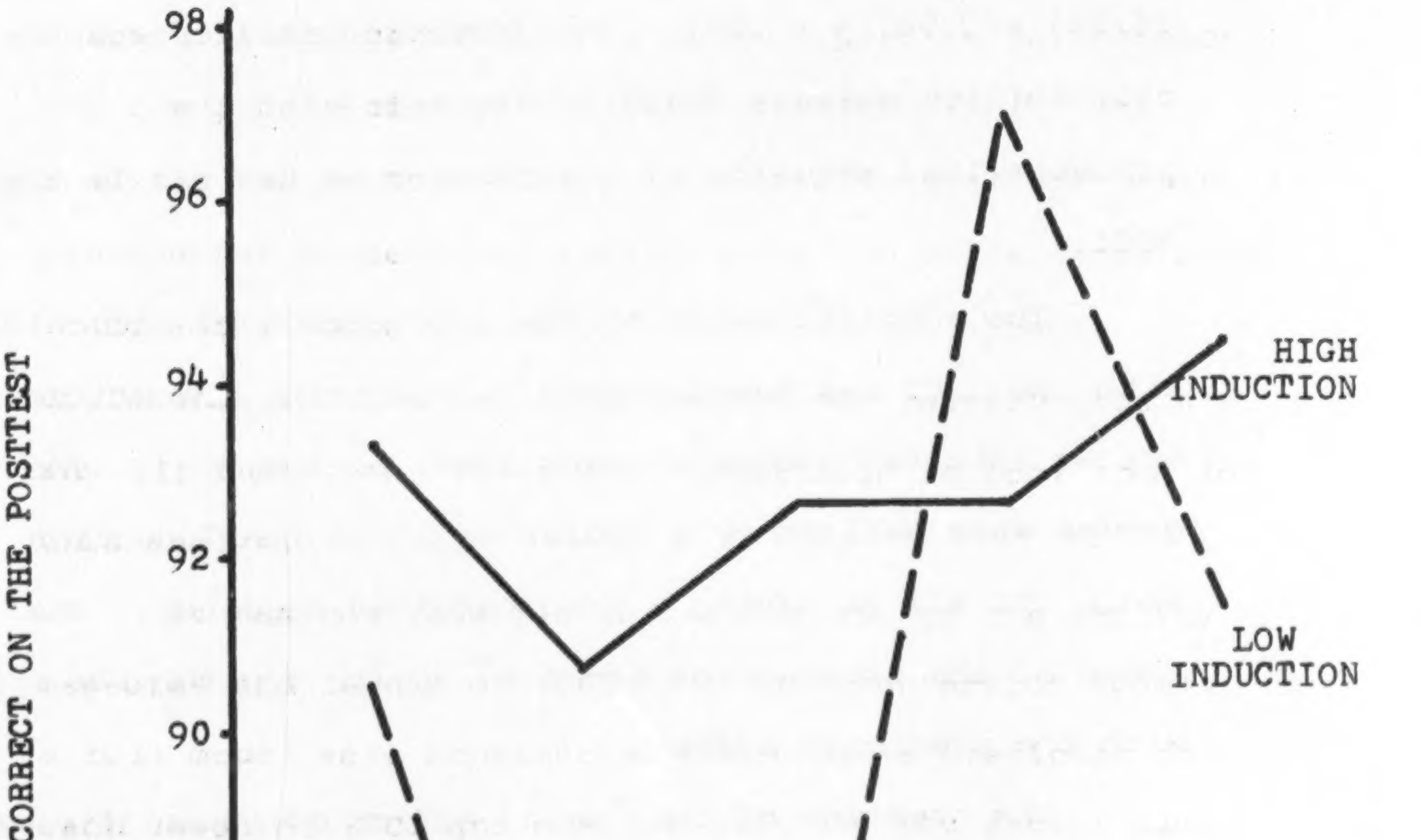


Figure 6. Interaction between Induction and the HSCI for a preselected sequence.

The criterion scores for the preselected sequence group were split into two groups defined as being above or below the median Memory score for the total group. A two-tail t test indicated a difference ($t = 2.39$, $df = 96$, $p < .02$) between these groups. A plot of mean criterion performance for the two Memory groups by the HSCI (Figure 7) indicated consistently a higher performance for the higher Memory scores.

Test of Hypothesis 4

Table 3 indicated the lowest performance of all the groups which studied the science was for group SS, and group C appeared to have a relatively high level of performance. A test of the mean differences between these groups yielded a highly significant result ($t = 3.61$, $df = 58$, $p < .001$) for the posttest total percent correct, and ($t = 3.70$, $df = 58$, $p < .001$) for the total weighted errors on the posttest.

Obviously a large percentage of the answers on the posttest can be "guessed" after observing the trends produced by the feedback procedure, but there still remains a highly significant number of items which are difficult to answer correctly without instruction.

It would have been desirable to have used analysis of variance techniques, as in testing the first two hypotheses; but group SS failed to meet sampling assumptions on the HSCI factor. By interacting with the materials each *S* determined his sequence rather than being

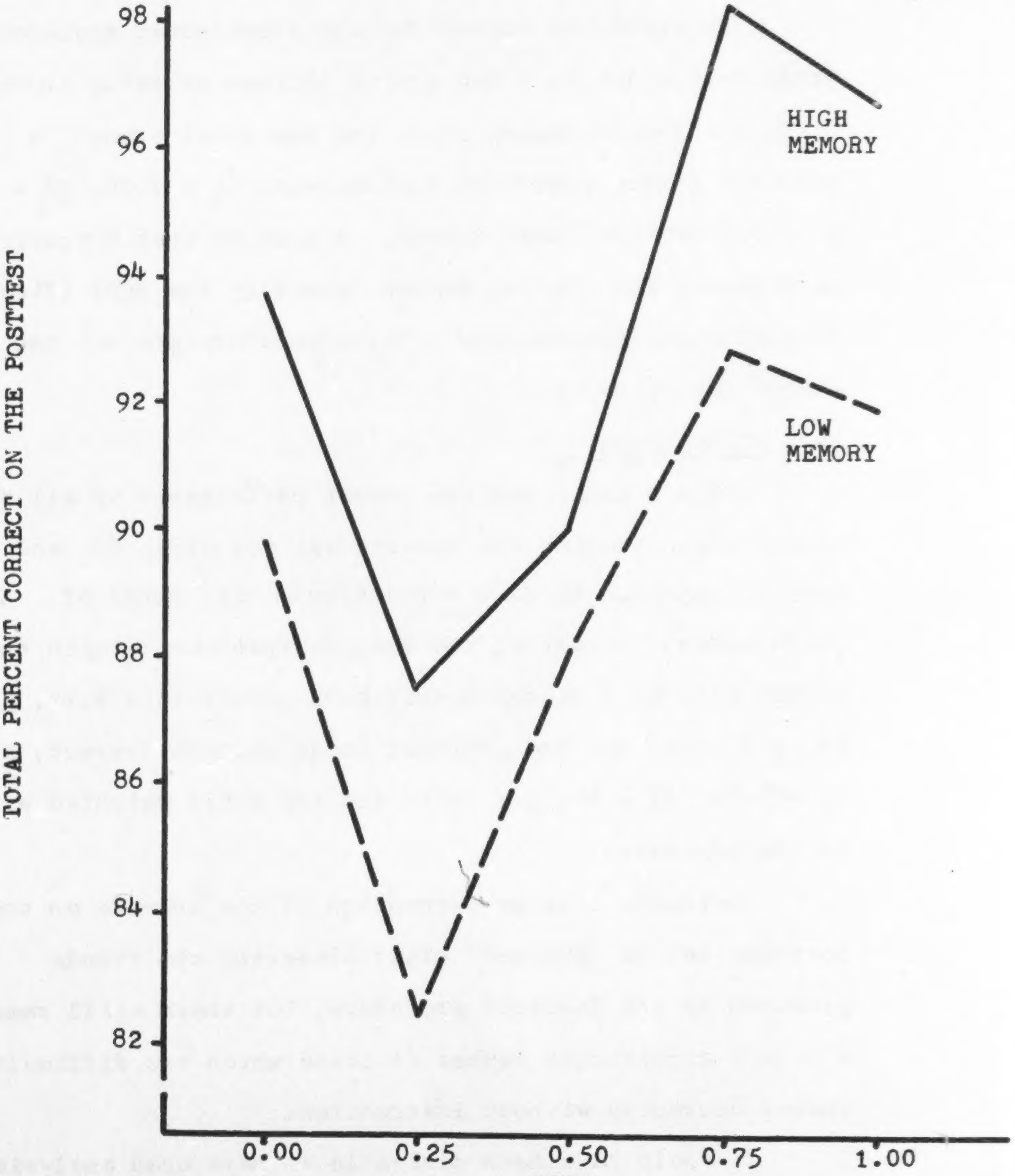


Figure 7. Relationship between Memory and the HSCI for a preselected sequence.

randomly assigned a sequence and corresponding value of the HSCI. The only index of the linear relationship of the HSCI to performance for group SS was the lack of correlation of the HSCI to the total percent correct for the posttest (r = 0.03).

Disregarding classification on the HSCI, two-tail t tests were computed for the mean differences between groups Y and SS. Contrary to Hypothesis 4, group Y was found to have superior performance. The total percent correct on the posttest approached but did not quite reach a level of significance ($t = 1.87$, $df = 102$, $p < .10$), but the total weighted errors on the posttest was significant ($t = 2.16$, $df = 102$, $p < .05$). No differences were detected between groups Y and SS on the retention test, or transfer test.

The other prediction was for a difference in the attitude toward the task. No difference in total attitude scale score was found. Of all the items on the attitude scale only item three discriminated the groups ($t = 2.06$, $df = 93$, $p < .05$), but the result was in the opposite direction to that predicted. A more positive attitude was indicated by group Y.

The difference which was detected between group Y and SS would seem to be attributable to the difference between self-selecting a sequence and being forced through a sequence. Table 1 showed that the SS and Y groups also differed in respect to the presence of a diagramatic representation of the science which was the only difference between groups FR and $F\bar{R}$. Since no difference was found between groups FR and $F\bar{R}$ it seems reasonable to infer the difference between groups SS and Y was not due to the presence of the task representation.

Test of Hypothesis 5

A significant positive relationship ($\underline{r}$ = 0.41, $\underline{p}$ < .01) between total percent correct on the posttest and General Reasoning scores was found. A positive but smaller correlation ($\underline{r}$ = .22) was found for $\underline{Ss}$ having a preselected sequence.

Exploratory Results

In addition to the results which have been reported under the sections on the test of the hypotheses, other criteria were used. Table 5 gives the results of the analyses for hypothesis one for number of errors on rules three through ten of the posttest, total percent correct on the retention test, total correct on the transfer test, and scores on the attitude questionnaire items one through ten. The results for Hypotheses two and four are summarized in Table 6.

Total percent correct on the posttest correlated 0.08 and 0.49 for group SS and 0.22 and 0.32 for the preselected sequence subjects with Memory and Induction respectively.

Table 5

Exploratory Results for Hypothesis 1

Criterion	Analysis of Variance with Groups FR & $F\bar{R}$. Effects of the HSCI Factor.	Analysis of Variance with Groups F & Y. Effects of the HSCI Factor.	Comparison of means for HSCI=1.00 & HSCI≠1.00 in Group $F\bar{R}$.
Total Posttest Errors on			
Rule 3			
Rule 4		$F(4/94) = 2.77$, $p < .05$	
Rule 5			$t=3.25$, $df=24$, $p<.01$
Rule 6	$F(4/42) = 3.10$, $p < .05$	$F(4/94) = 4.89$, $p < .005$	$t=4.25$, $df=24$, $p<.001$
Rule 7			$t=4.10$, $df=24$, $p<.001$
Rule 8			$t=2.14$, $df=24$, $p<.05$
Rule 9			
Rule 10		$F(4/94) = 2.98$, $p < .05$	
Total Percent Correct on the Retention Test			$t=2.11$, $df=21$, $p<.05$
Total Correct on the Transfer Test	$F(4/32) = 2.68$, $p < .05$		$t=3.52$, $df=23$, $p<.05$
Attitude Scale			
Item 1			
Item 2			
Item 3		$F(4/80) = 2.66$, $p < .05$	
Item 4			
Item 5			
Item 6		$F(4/80) = 3.08$, $p < .05$	
Item 7			
Item 8			
Item 9			
Item 10			

Table 6

Exploratory Results for Hypotheses 2 & 4

Criterion	Hypothesis 2	Hypothesis 4
Total Posttest Errors on		
Rule 3		$\underline{t} = 2.01$, $\underline{df} = 102$, $\underline{p} < .05$
Rule 4	$\underline{t} = 2.14$, $\underline{df} = 47$, $\underline{p} < .05$	
Rule 5		
Rule 6	$\underline{t} = 2.07$, $\underline{df} = 47$, $\underline{p} < .05$	
Rule 7		
Rule 8		
Rule 9		$\underline{t} = 2.84$, $\underline{df} = 102$, $\underline{p} < .01$
Rule 10	$\underline{t} = 2.12$, $\underline{df} = 47$, $\underline{p} < .05$	
Total Percent Correct on the Retention Test		
Total Correct on the Transfer Test		
Attitude Scale		
Item 1		
Item 2		
Item 3		
Item 4		
Item 5		
Item 6	$\underline{t} = 2.72$, $\underline{df} = 38$, $\underline{p} < .01$	
Item 7		
Item 8		
Item 9		
Item 10		$\underline{t} = 2.06$, $\underline{df} = 93$, $\underline{p} < .05$

CHAPTER 4

DISCUSSION

The purpose of this study was to investigate instructional sequence. Specifically it was desired to investigate ways in which a task could be organized or structured for presentation to students. This question included the possibility that students could organize their own learning sequence as well as investigating ways in which materials could be presequenced for the student. The investigation also included the cognitive skills or abilities which would aid a student in learning a task by different sequences. Since no methods which existed for defining a task's structure seemed adequate, an information-processing analysis was defined.

The information-processing analysis proved to be a reliable and an objective method in the sense that a number of persons independently arrived at the same sequence of steps once the elements of the task structure were defined. The question of the validity of this analysis was not as clearly answered. It was predicted that if this information-processing analysis defined a sequence of instruction which improved learning performance, then as an index of conformity to hierarchical sequence (HSCI) decreased from 1.00 to 0.00 performance would correspondingly decrease. This test of the validity of the analysis assumed that the HSCI gives an ordinal measure of the degree of conformity to this analysis. Any departure from the predicted result could be due to an invalid analysis, an invalid HSCI, both the analysis and the HSCI invalid, or an invalid assumption that hierarchical sequences facilitate learning.

This study did not support the Neidermeyer's (1968) conclusion that instructional sequence for relatively short programs is of minimal importance.

In general, a covariation between the HSCI and performance was found for preselected sequences. This positive contribution for a hierarchical instructional sequence held over time and through the transfer test as well as yielding a more positive attitude for some Ss. The only seeming inconsistency of this relationship was the performance change at HSCI = 0.00. Although not found to be a statistically significant change, the same effect was independently observed in all predetermined sequence groups and in a pilot study. If this inconsistency were a real effect, then several possible explanations could be given. The HSCI may not accurately define the degree of conformity of the instructional sequence to the task analysis. There was, however; the predicted relationship over a major portion of the range of the HSCI (0.25-1.00). The HSCI has a value of 0.00 only when the instructional sequence is completely reversed from that of the information-processing analysis structure. This point where HSCI = 0.00 is easy to define independently of the HSCI as it is to define a sequence which progresses in an ordinal fashion through the structure. The only descriptive utility of the HSCI is for the interim range of disordinal sequences.

There may have been a pecularity of the terminal objective or of the entire task which had a facilitative effect for a completely reversed sequence. This alternative explanation could only be answered by a similar experimental design using another task.

It seems unlikely that the information-processing analysis is completely invalid, since performance tended to covary with the index of proximity to the defined structure, the HSCI.

The HSCI should not be viewed as a tool of relevance to the design of real instructional programs in itself. It was developed to determine the proximity to a hierarchical sequence as determined by the information-processing analysis, and hence to provide a means to validate the analysis.

To obtain enough Ss for a meaningful analysis of the abilities the groups having a predetermined sequence were combined. No difference on any dependent measure, except the time spent studying the science materials, was found among these three groups; so the decision to combine them seemed reasonable. The statistically significant ordinal interaction between the sequence of instruction, as defined by the HSCI, and the Induction scores had the generally expected shape. It was expected that an individual who had a high measure on the Induction ability would be less affected by a disordinal sequence than would an individual having a low measure on this ability. Perhaps this ability facilitated the inducing of ordering of steps in the composite task which were not presented in an ordered manner. As the sequence of instruction became more ordinal, a larger number of the prerequisite steps were taken before the higher level steps thus reducing a reliance on an Induction ability.

The Memory ability measure was not found to interact with the HSCI, but a higher level seemed to increase performance scores relatively equally for any value of the HSCI. As Ss Memory ability increased his performance increased. This ability might have helped S remember the verbal rules which were taught, rather than the order of rules per se. As Payne & Krathwohl (1967) suggested, Memory and Induction made a positive contribution to performance.

A self-selected sequence of instruction did not produce a high level of performance as some studies had indicated it might. The lack of correlation between the HSCI and performance for a self-selected sequence indicates the lack of a systematic effect of sequence on performance when S choses his own sequence. It was found that self-selection of sequence led to lower performance than a hierarchical predetermined sequence. The implication of this finding is that a task analysis is a worthwhile endeavor; since it can lead to the definition of a hierarchical presentation sequence which increases performance, at least for some learner populations.

It would be difficult to explain the low scores for group SS by stating that the representation had no meaning for them; thus they had nothing to assist them in selecting their sequence. Group Y was given no representation, and the randomly matched S in group Y recieved the same steps in the same sequence as the S from group SS to which he had been paired. The performance of group Y was significantly higher than that of group SS. It would seem that having the freedom to select one's own sequence and repeat steps which were unclear would be more meaningful and aid learning more than being shown steps in a sequence which bore no relationship to one's previous performance, but the data do not bear this out.

The task used in this study differed in several possible ways from the tasks used in the studies finding a benefit for learner-generated sequences. This task used in this study was completely new to all Ss. In some of the previous studies (Mager, 1961; Mager & McCann, 1961) the Ss were familiar with some of the large units in the task. In the study by Campbell and Chapman (1967) the learner-generated sequences were of only large units of a possibly non-hierarchical task. The smaller steps were given as units of presequenced materials, and even then group discussions followed the individual learning sessions. This study was also conducted over a shorter time span than the studies finding a positive contribution for self-selected sequences. Learners may need experience and training to make self-selection of sequence beneficial.

Self-selection of sequence may be found to be a beneficial techinique when used for selecting and sequencing missing units as in review, or when the task is not hierarchical, or when the steps to be sequenced are large steps composed of smaller presequenced materials, or when used over a longer time span, or any combination of the above. The technique of learner-generated sequence was unsuccessful when the task was a relatively short, abstract, mathematical-scientific system taught as small steps and of which the students had no prior experience.

As was expected there was a strong positive relationship between performance for group SS and the Reasoning ability. It was expected that this measure would aid in organizing and structuring the task to facilitate performance. Induction was also highly related to performance for this group. It could be that by not following this structure this ability was called upon in a similar manner to that described for the preselected sequence group. It could also have been that due to a lower level of learning, Induction was important in inducing the necessary behaviors from the posttest feedback procedures. The Memory ability seemed to be unrelated to performance for group SS.

APPENDIX A

CONCEPTS OF THE XENOGRADE SCIENCE

Alphons	**Small particles which may cling to the surface of the nucleus or revolve around the nucleus.**
Satellite	**A cluster of one or more alphons which revolves around the nucleus.**
Alphon Count, Nucleus (ACN)	**The number of alphons which are inside the nucleus.**
Alphon Count, Satellite (ACS)	**The number of alphons in the cluster which makes up the satellite.**
Force Field (FF)	**A field of force which has differential effects on a Xenograde system.**
Blip	**The collision of a satellite with its nucleus.**
Orbit	**The path of the revolving satellite.**
Distance	**The number of units between the satellite and the nucleus.**
Velocity	**The speed of the satellite moving towards or away from the nucleus.**
Time	**The number of units of time since the Xenograde system entered a force field.**

RULES OF THE XENOGRADE SCIENCE

1. If FF = 1, the decrease in distance between each time is equal to ACS.
2. If ACS = 1, the decrease in distance between each time is equal to FF.
3. The decrease in distance between each time is equal to the value of FF x ACS.
4. ACN and ACS cannot change unless a blip occurs.
5. When the distance becomes zero a blip is recorded whose value is equal to the value of the time.
6. When the blip time is even, ACN decreases by one while ACS increases by one.
7. When the blip time is odd, ACN increases by one while ACS decreases by one.
8. If the blip time is even and ACN was zero on the previous line, ACN and ACS do not change.
9. After a blip occurs, the distance begins to increase each time by the value of FF x ACS.
10. After a blip, the distance increases to its original value and then begins to decrease again.

THE TERMINAL OBJECTIVE

Given the initial conditions of ACN, ACS, Distance, and Force Field (FF), the student will be able to produce a complete table of Xenograde readings line by line from time zero up to any specified time.

APPENDIX B

Posttest-Retention Test Form A*

FF = 2

Time	ACN	Blip	Distance	ACS
0	2		12	1
1	2(R4)		10(R3)	1(R4)
2	2(R4)		8(R3)	1(R4)
3	2(R4)		6(R3)	1(R4)
4	2(R4)		4(R3)	1(R4)
5	2(R4)		2(R3)	1(R4)
6	1(R6)	6(R5)	0(R3)	2(R6)
7	1(R4)		4(R9)	2(R4)
8	1(R4)		8(R9)	2(R4)
9	1(R4)		12(R9)	2(R4)
10	1(R4)		8(R3)	2(R4)
11	1(R4)		4(R3)	2(R4)
12	0(R6)	12(R5)	0(R3)	3(R6)
13	0(R4)		6(R9)	3(R4)
14	0(R4)		12(R9)	3(R4)
15	0(R4)		6(R3)	3(R4)
16	0(R8)	16(R5)	0(R3)	3(R8)
17	0(R4)		6(R9)	3(R4)
18	0		6	3

****

FF = 2

Time	ACN	Blip	Distance	ACS
0	2		60	6
1	2(R4)		48(R3)	6(R4)
2	2(R4)		36(R3)	6(R4)
3	2(R4)		24(R3)	6(R4)
4	2(R4)		12(R3)	6(R4)
5	3(R7)	5(R5)	0(R3)	5(R7)
6	3(R4)		10(R9)	5(R4)
7	3(R4)		20(R9)	5(R4)
8	3(R4)		30(R9)	5(R4)
9	3(R4)		40(R9)	5(R4)
10	3(R4)		50(R9)	5(R4)
11	3(R4)		60(R9)	5(R4)
12	3(R4)		50(R3)	5(R4)
13	3(R4)		40(R3)	5(R4)
14	3(R4)		30(R3)	5(R4)
15	3(R4)		20(R3)	5(R4)
16	3(R4)		10(R3)	5(R4)
17	4(R7)	17(R5)	0(R3)	4(R7)
18	4(R4)		8(R9)	4(R4)

*With rule (R_n) scoring this item in parenthesis

Posttest-Retention Test Form B*

FF = 5

Time	ACN	Blip	Distance	ACS
0	2		60	2
1	2(R4)		50(R3)	2(R4)
2	2(R4)		40(R3)	2(R4)
3	2(R4)		30(R3)	2(R4)
4	2(R4)		20(R3)	2(R4)
5	2(R4)		10(R3)	2(R4)
6	1(R6)	6(R5)	0(R3)	3(R6)
7	1(R4)		15(R9)	3(R4)
8	1(R4)		30(R9)	3(R4)
9	1(R4)		45(R9)	3(R4)
10	1(R4)		60(R9)	3(R4)
11	1(R4)		45(R3)	3(R4)
12	1(R4)		30(R3)	3(R4)
13	1(R4)		15(R3)	3(R4)
14	0(R6)	14(R5)	0(R3)	4(R6)
15	0(R4)		20(R9)	4(R4)
16	0(R4)		40(R9)	4(R4)
17	0(R4)		60(R9)	4(R4)
18	0(R4)		40(R3)	4(R4)
19	0(R4)		20(R3)	4(R4)
20	0(R8)	20(R5)	0(R3)	4(R8)
21	0(R4)		20(R9)	4(R4)

****

FF = 2

Time	ACN	Blip	Distance	ACS
0	1		24	4
1	1(R4)		16(R3)	4(R4)
2	1(R4)		8(R3)	4(R4)
3	2(R7)	3(R5)	0(R3)	3(R4)
4	2(R4)		6(R9)	3(R7)
5	2(R4)		12(R9)	3(R4)
6	2(R4)		18(R9)	3(R4)
7	2(R4)		24(R9)	3(R4)
8	2(R4)		18(R3)	3(R4)
9	2(R4)		12(R3)	3(R4)
10	2(R4)		6(R3)	3(R4)
11	3(R7)	11(R5)	0(R3)	2(R7)
12	3(R4)		4(R9)	2(R4)

---

*With rule (R_n) scoring this item in parenthesis

Name ______________________________ Instructor ________________
(Last) (First)

Date ______________________

Transfer Test for Xenograde Science

In this test you will be asked to infer three new rules of the science. Page 2 of the booklet contains instructions and two sample tables demonstrating the three new rules. Page 3 contains nine test items to assess your inferences.

You will have 15 minutes to study the sample tables and answer the nine test questions. You will be told when 5 minutes remain.

You may refer to the sample tables while taking the test items if desired.

Fill in your answers in the blanks provided.

TURN TO PAGE TWO NOW.

Instructions for Transfer Task

For the transfer task you will be given two Xenograde tables which will serve as examples for three new rules of the Science. Your task will be to study these tables in order to discover the additional rules.

When you feel you have discovered the rules, go to the test items where you will be asked to use the rules to predict:

1. What affect a negative force field will have upon alphon activity.
2. When a satellite will disappear.
3. What the next distance will be if the distance increment would take the satellite past its original orbit.

Example 1

FF = -2

System Time	ACN	Blip	Satellite Distance	ACS
0	2		12	3
1	2		6	3
2	3	2	0	2
3	3		4	2
4	3		8	2
5	3		12	2
6	3		8	2
7	3		4	2
8	4	8	0	1
9	4		2	1
10	4		4	1
11	4		6	1
12	4		8	1
13	4		10	1
14	4		12	1
15	4		10	1
16	4		8	1
17	4		6	1
18	4		4	1
19	4		2	1
20	5	20	0	0

The Satellite disappeared at time 20.

Example 2

FF = 2

System Time	ACN	Blip	Satellite Distance	ACS
0	2		12	3
1	2		6	3
2	1	2	0	4
3	1		8	4
4	1		8	4
5	2	5	0	3
6	2		6	3
7	2		12	3
8	2		6	3
9	3	9	0	2
10	3		4	2
11	3		8	2
12	3		12	2
13	3		8	2
14	3		4	2
15	4	15	0	1
16	4		2	1
17	4		4	1
18	4		6	1
19	4		8	1
20	4		10	1
21	4		12	1
22	4		10	1
23	4		8	1
24	4		6	1
25	4		4	1
26	4		2	1
27	5	27	0	0

The Satellite disappeared at time 27.

TRANSFER TEST ITEMS

FF = -3

System Time	ACN	Blip	Satellite Distance	ACS
.	.		.	.
.	.		.	.
.	.		.	.
14	5		6	1
15	5		3	1
16	■	16	0	■

Will the satellite disappear? no
(Yes or no)

FF = -5

System Time	ACN	Blip	Satellite Distance	ACS
0	-		25	-
.	.		.	.
.	.		.	.
.	.		.	.
5	2		0	2
6	2		10	2
7	2		20	2
8	2		■	2

At time 8 the value of the distance is 20.

FF = 4

System Time	ACN	Blip	Satellite Distance	ACS
.	.		.	.
.	.		.	.
.	.		.	.
37	2		8	1
38	2		4	1
39	■	39	0	■

Will the satellite disappear? yes
(Yes or no)

FF = 4

System Time	ACN	Blip	Satellite Distance	ACS
.	.		.	.
.	.		.	.
.	.		.	.
33	4		24	3
34	4		12	3
35	■	35	0	■

At time 35 the value of ACN = 5

and ACS = 2.

FF = -1

System Time	ACN	Blip	Satellite Distance	ACS
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
25	8		10	5
26	8		5	5
27	■	27	0	■

At time 27 the value of ACN = 7

and ACS = 6.

FF = 2

System Time	ACN	Blip	Satellite Distance	ACS
0	-		15	-
.	.		.	.
.	.		.	.
.	.		.	.
24	5		0	3
25	5		6	3
26	5		12	3
27	5		■	3

At time 27 the value of the distance is 12.

FF = 6

System Time	ACN	Blip	Satellite Distance	ACS
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
57	8		12	2
58	8		6	2
59	■	59	0	■

Will the satellite disappear? no
(Yes or no)

FF = -2

System Time	ACN	Blip	Satellite Distance	ACS
0	-	-	18	-
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
43	1		8	2
44	1		12	2
45	1		16	2
46	1		■	2

At time 46 the value of the distance is 16.

FF = -3

System Time	ACN	Blip	Satellite Distance	ACS
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
40	7		42	7
41	7		21	7
42	■	42	0	■

At time 42 the value of ACN = 8

and ACS = 6.

Name ______________________________ Experiment No. __________

ATTITUDE QUESTIONNAIRE TOWARD XENOGRADE SCIENCE

It is felt that the aspects of enjoyment and sense of worth are usually overlooked in automated instruction. Please answer the following ten items as truthfully as you can. Your instructor will not be shown your responses, but rather they will be used to indicate the feeling of a group toward the use of computer-assisted instruction in science learning.

Read each of the following ten statements carefully then mark an "X" in the box under the column corresponding to whether you strongly agree, agree, disagree, or strongly disagree with the statement.

	strongly agree	agree	disagree	strongly disagree
1. I would recommend the kind of learning experience that I had to my friends.				
2. I would like to learn more often by the computer-based instruction.				
3. I would prefer being taught by another method of instruction (forced sequence, self-selected sequence, discovery, deductive, etc.				
4. I feel that I learned a great deal about computer-assisted instruction in science learning.				
5. I enjoyed participating in the imaginary science study.				
6. I would recommend that my instructor require all his students to learn about the science of Xenograde systems.				
7. I would like to learn more about the science of Xenograde systems.				
8. I feel that learning about the science of Xenograde systems was fun.				
9. I would like to take other courses by computer-assisted instruction.				
10. I feel that what I did will be helpful to me as a teacher.				

To help us better design instructional programs, please write that aspect of your experience with the Xenograde program which you most enjoyed, and that aspect which you least enjoyed. ______________________________

____

____

____

APPENDIX C

THE LINEAR MODEL

It is the purpose of this technical appendix to demonstrate, by means of equations and graphs, the method of testing the hypotheses of ability by instructional sequence interaction and the contributions of the level of ability to performance.

The full model for describing the data is:

$$P = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + a_4X_4$$
$$+ a_5A + a_6X_1*A + a_7X_2*a + a_8X_3*A$$
$$+ a_9X_4*A + E\text{, where}$$

P is the criterion vector containing the total percent correct on the posttest for all Ss,

U is a unit vector containing all ones,

X_n is a vector containing a one if the corresponding element in P is a score for a person having sequence n (where n = 1 for HSCI = 0.00, n = 2 for HSCI = 0.25, n = 3 for HSCI = 0.50, and n = 4 for HSCI = 0.75),

A is a vector containing the factor score for the ability (Memory or Induction) for the person having the corresponding criterion score in P,

X_n*A is a direct product vector of A and X_n, and

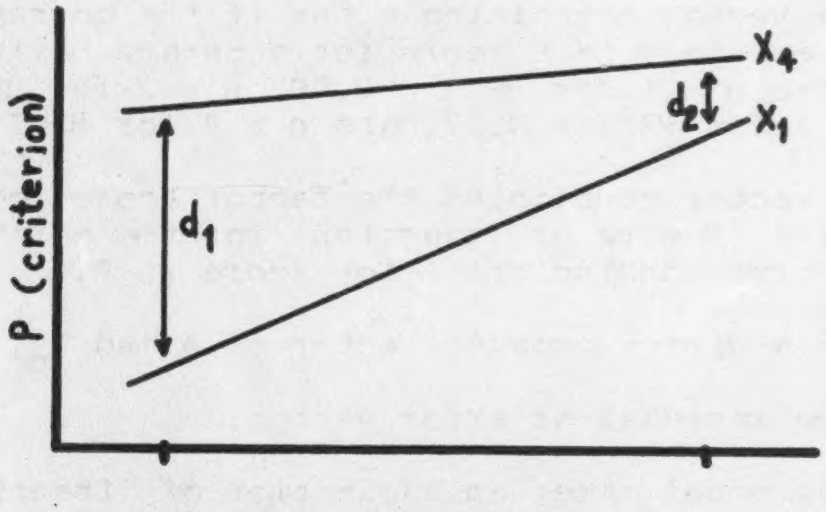
E is the residual or error vector.

This model makes an assumption of linearity of regression for the criterion (P) upon A. This linearity assumption means that for each unit increase in A there is a corresponding constant change in the average value of P. This assumption is inherent and not testable using the full model given above.

It should be noted that there is no explicit vector defining Ss having HSCI = 1.00 (X_5). Since $X_1 + X_2 + X_3 + X_4 + X_5 = U$, X_5 is said to be a linear combination of the vectors U and X_1 through X_4. Inclusion of X_5 would lead to redundancies among the predictor variables and hence to a non-unique solution of the weights(a_ns).

Hypotheses are tested by making comparisons of the residual (E) vectors in the full and restricted models as outlined by Bottenberg & Ward (1963).

In the following graph the ordinate represents the criterion scores and the absissa represents the ability. High scores are away from the origin. The two graphed lines (X_1 & X_4) represent the regression lines of two different HSCI groups on the criterion.



A (ability)

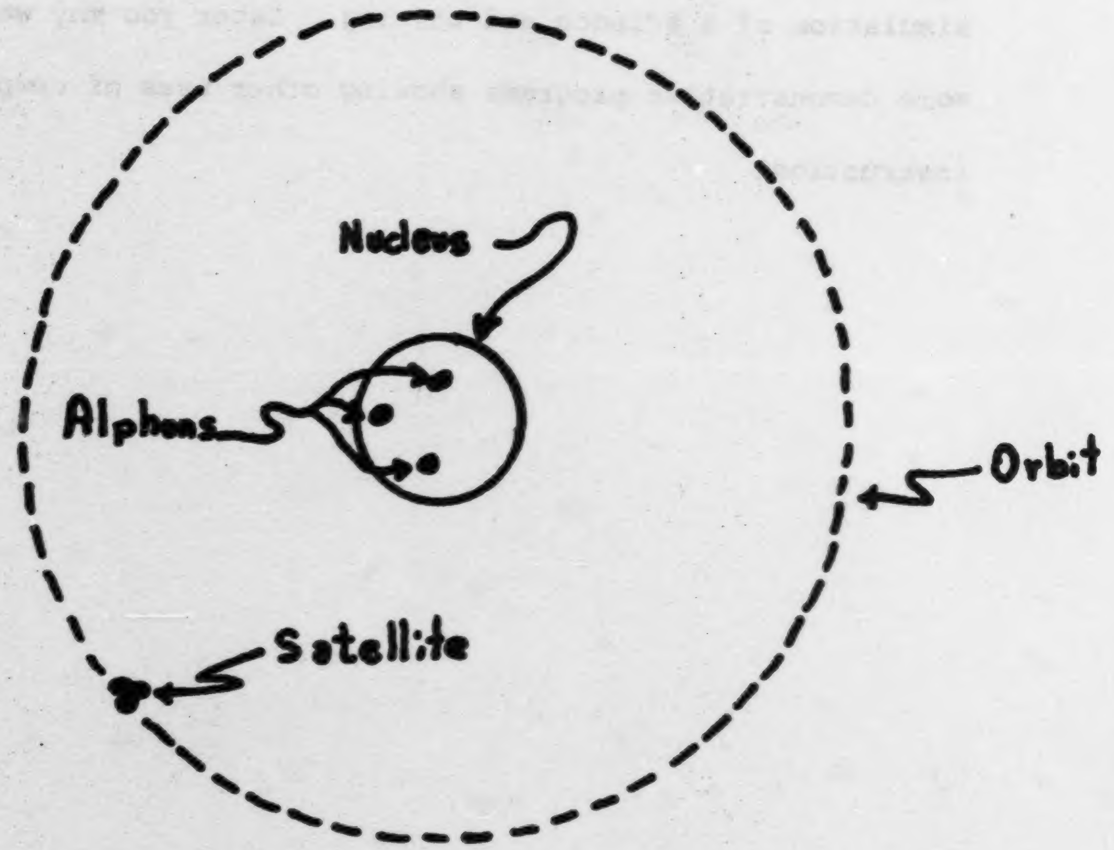
No interaction exists between ability (A) and the HSCI (X_n) if $d_1 = d_2$, which implies that the slopes of the two lines are equal. In addition, no contribution of a different level of HSCI is significant if d_1 and d_2 are zero, which means the lines are colinear.

By constructing equations of expected values for the points and setting the slopes of all regression lines equal, one arrives at the following restriction to test the interaction. Only if the restriction that $a_6 = a_7 = a_8 = a_9$ significantly increases the error of prediction may the hypothesis of no interaction be rejected. The next appropriate test would be to see if there is a "main effect" for the HSCI. It can be shown that the hypothesis of colinear regression lines (no "main effects") may be rejected if the restriction $a_1 = a_2 = a_3 = a_4$ produces a restricted model significantly different from the full model. The question of "main effects" is not appropriate if an interaction is found.

APPENDIX D

THE INSTRUCTIONAL PROGRAM CONCERNS AN IMAGINARY SCIENCE CALLED THE SCIENCE OF XENOGRADE SYSTEMS. A XENOGRADE SYSTEM CONSISTS OF A NUCLEUS WITH AN ORBITING SATELLITE. THE SATELLITE IS COMPOSED OF SMALL PARTICLES CALLED ALPHONS WHICH MAY ALSO RESIDE IN THE NUCLEUS. UNDER CERTAIN CONDITIONS A SATELLITE MAY COLLIDE WITH THE NUCLEUS. WHEN SUCH A COLLISION OCCURS, A "BLIP" IS SAID TO HAVE OCCURRED, AND THE SATELLITE MAY EXCHANGE ALPHONS WITH THE NUCLEUS. THE SCIENCE DEALS WITH THE LAWS BY WHICH THE ACTIVITY OF SATELLITES AND ALPHONS MAY BE PREDICTED.

THE FOLLOWING DIAGRAM IS ONE WAY OF CONCEPTUALIZING A XENOGRADE SYSTEM.



JUSTIFICATIONS

Your participation in the study of Xenograde Systems will enable the research staff of this laboratory to study how people learn a science and how they form and test hypotheses.

The time you spend will not give you an encyclopedia of facts useful outside this course, but it may improve your skills of observation, inference, prediction, formulating hypotheses, controlling and manipulating variables, interpreting data, formulating models, and a better way of approaching scientific problems. The study you are about to undertake has the challenge of a complex game and should be interesting in its own right.

The interaction with the materials in this study will give you some idea of the potential of computer-assisted instruction in simulation of a science and testing. Later you may want to sample some demonstration programs showing other uses of computer-assisted instruction.

BACKGROUND MATERIAL FOR XENOGRADE SYSTEMS

Very little was known about Xenograde Systems until the Xenograde Recorder was invented. Figure 1 shows a picture of the Xenograde System Recorder. This device was invented by the late Professor O.T.R. Limits (his untimely death was caused by a mysterious explosion which has been traced tentatively to a chain reaction caused by an unfortunate combination of my Xenograde Systems).

The Xenograde Recorder makes a record on a continuous roll of ruled paper. There is a trace for each satellite which plots distance from the nucleus by time. The recording indicates the time at which satellites collide with the nucleus. These collisions are called blips.

Because Xenograde System Recorders are far too expensive to provide one for each student, we have used the computer to simulate the activity of the Xenograde System. The computer allows us to present on the CRT a more convenient display than that provided on the paper that issues from the Xenograde System Recorder. This display is in tabular form.

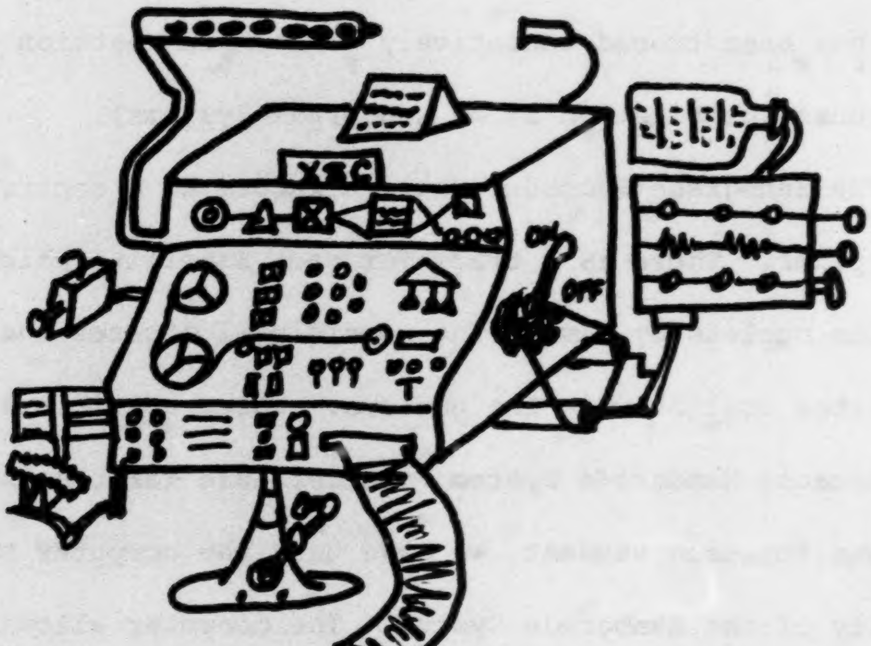


Figure 1. Sketch of a Xenograde System Recorder

INSTRUCTIONS FOR READING THE DISPLAYS

In taking this course, you will need to be able to read a tabular display on the CRT which records the activity of the particles making up a Xenograde System.

Figure 2 is a sample display.

FF = 2

System Time	ACN	Blip Time	Satellite Distance	ACS
0	2		24	3
1	2		18	3
2	2		12	3
3	2		6	3
4	1	4	0	4
5	1		8	4
6	1		16	4

Figure 2. Sample display of a Xenograde table.

The symbols stand for the following:

F.F. - Force field - Physically this can be thought of as an area in space, which if entered by an Xenograde System, will exert certain predictable effects on the system. The strength of the force field can be measured and given numerical values. The effect of the force field on the Xenograde System is based on the strength of the force field.

TIME - This column serves as a clock which provides a basis for presenting the state of the system at small sequential intervals of time. It is increased by a value of 1 (one) with each reading. Notice that time always starts at time 0 (zero).

ACN - Alphon Count of the Nucleus. As the name suggests, the numerical values in the column under ACN refer to the number of alphons that are located in the nucleus at any given time. For example, in the figure the number of alphons on the nucleus at time 2 is 2 while the number of alphons on the nucleus at time 6 is 1.

BLIP TIME - In the column under this heading are recorded the value of the time clock when a blip occurs, that is when a satellite collides with the nucleus. In Figure 2 you will notice that such a collision occurred at time 4.

SATELLITE DISTANCE - The values recorded in the column under this heading refer to the number of units of distance between the satellite and the nucleus. From figure two you will notice that the satellite is 24 units from the nucleus at time 0 while it is only 6 units from the nucleus at time 3.

ACS - Alphon count of the Satellite. The values recorded in the column under this heading refer to the number of alphons which make up the satellite at any given time. For example, in the Figure, the number of alphons in the satellite at time 2 is 3 while there are 4 alphons in the satellite at time 5.

⋮ - A series of three dots in any column refer to a series of values that have been skipped. For example, if the time column starts with three dots followed by the number 24, then all the values from time 0 to time 24 have been skipped.

INSTRUCTIONS FOR SELF SEQUENCING GROUP

After signing on the terminal a diagram of the subject matter hierarchy will be displayed on the CRT (Cathode Ray Tube). This diagram is also reproduced in Figure 3. Table 1 gives behavioral objectives for each of these ten lessons. Please refer to it when deciding which lesson you wish to take next. When you have decided which lesson to take type in the letter corresponding to this lesson and instruction will follow. Do not necessarily start at one point and work through the lessons in a given order, but rather read all of the objectives and choose the next lesson based on what you feel you would like to take next.

After selecting a lesson a rule will be displayed on the image projector and a partial Xenograde table will appear on the CRT. The Xenograde table will be an example of how the rule operates. Your task will be to learn the rule and how it is applied in a Xenograde table. When you feel you have learned the rule and its application, type the word test.

You will then be given a series of 3 test items. These test items will consist of partial tables with missing values represented by a shaded box. You will be asked to predict the missing values by using the rule you have learned.

After typing in your answer and performing the ENTER function, you will automatically be given the next item. After taking the three test items, you will be told how many you answered correctly. The diagram of the science will be displayed next. It is up to you to decide if you want to repeat this lesson or attempt a different one.

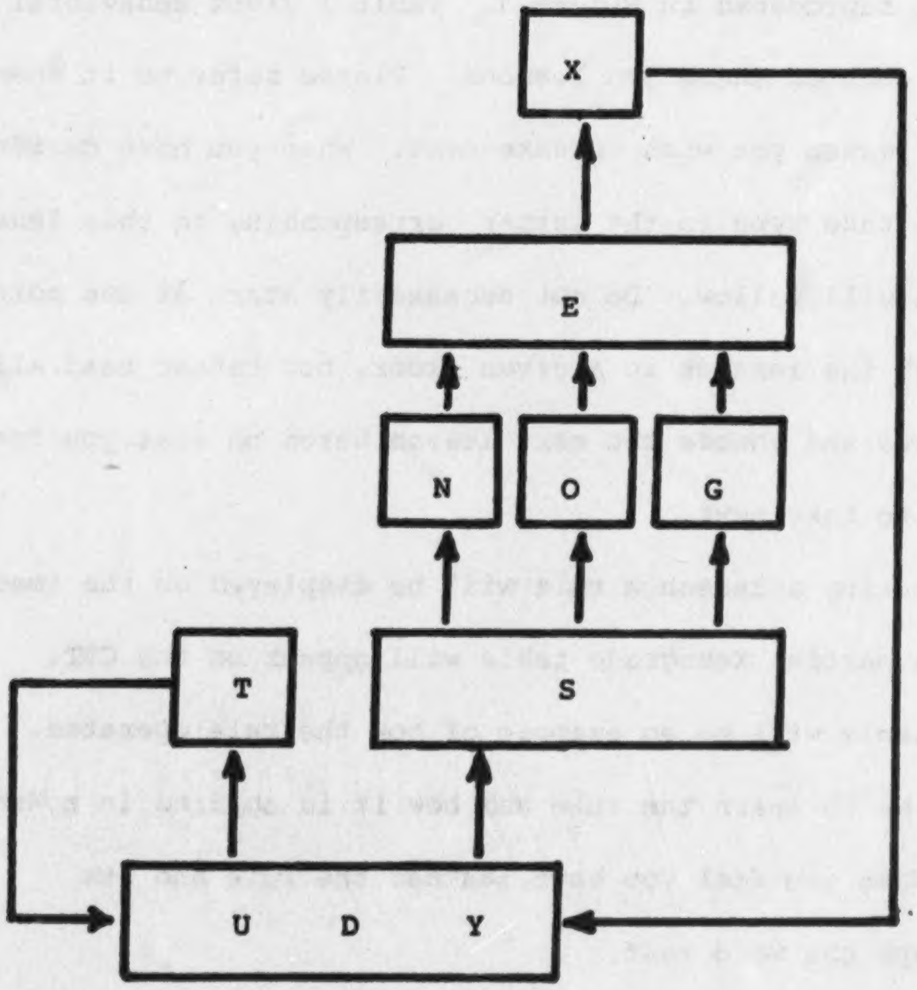

X
E
N
O
G
T
S
U D Y

Figure 3. Diagram of the hierarchy of skills for the Xenograde Science (lowest level at bottom).

If you repeat this lesson you will be given a different example and a different test. There are only five examples and tests for each lesson. If you have used all five and try to take more you will simply be told to try another.

Keep a record in the column provided on your sheet of objectives of the lessons that you have attempted and when you have taken at least one lesson per rule you may finish the instruction by typing a "Z" and take the post test. Be sure that you take at least one lesson per rule. This means you will have a minimum of ten lessons before taking the post test.

The post test will assess your ability to predict entries in a table of Xenograde readings line by line given the initial conditions. Since scores you make in learning this science will not affect your course grade, but will be used to answer research questions in education, we would appreciate it very much if you would refrain from discussing the details of the science and post test with fellow class mates who have not yet taken the course. Prior knowledge of the details of the course may confound the results and make the time you have spent in vain.

PLEASE NOTE: If you run into difficulty, it will be very helpful for you to refer back to this booklet. Try to relate the numbers in the tables to the physical diagram and the explanation found on the first page of this booklet.

Lesson Objectives

	Example					
Lesson	1	2	3	4	5	
X						Given the original satellite distance, the student should be able to predict to what maximum value the distance will increase.
E						Given that a blip has occurred, the student should be able to predict how the distance will begin changing.
N						Given that the blip time is even and ACN was zero on the previous line, the student should be able to predict how the values of ACN and ACS are affected.
O						Given that the blip time is odd, the student should be able to predict how the values of ACN and ACS are affected.
G						Given that the blip time is even, the student should be able to predict how the values of ACN and ACS are affected.
S						Given that a blip has occurred, the student should be able to give the time of its occurrence and the value of distance at this time.
T						Given that no blip has occurred, the student should be able to predict the values of ACN and ACS.
U						Given a previous distance, the student should be able to predict how FF and ACS will affect the values of distance.
D						Given that ACS = 1 and the value of the previous distance, the student should be able to predict how the value of FF will affect the distance.
Y						Given that FF = 1 and the value of the previous distance, the student should be able to predict how the value of ACS will affect the distance.

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